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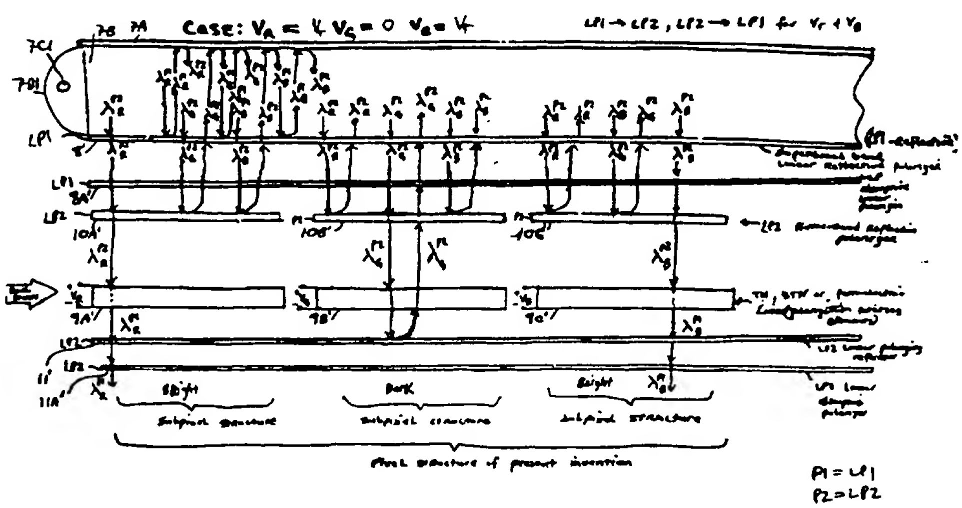

(57) Abstract

The spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements (9A', 9B', and 9C'), the pixel driver signals provided thereto are selected to produce "bright" output levels, the rec and blue subpixels of the exemplary pixel structure and a "dark" output level at the green subpixel level, and a broad-band absorptive linear polarizer (11A') is used in conjunction with eath broad-band polarizing reflective panel (11') in the LCD panel in order to provide improved image contrast in the images display therefrom.

intensity modulating elements, for spectral filtering the intensity modulated light rays transmitted therethrough, to form a color image for either direct or projection viewing. Examples of such prior art LCD panel systems are described in "A Systems Approach to Color Filters for Flat-Panel Displays" by J. Hunninghake, et al, published in SID 94 DIGEST (pages 407-410), incorporated herein by reference.

In color LCD panel design, the goal is to maximize the percentage of light transmitted from the backlighting structure through the color filtering array. However, using prior art design techniques, it has been impossible to achieve this design goal due to significant losses in light transmission caused by the following factors, namely: absorption of light energy due to absorption-type polarizers used in the LCD panels; absorption of light reflected off thin-film transistors (TFTs) and wiring of the pixelated spatial intensity modulation arrays used in the LCD panels; absorption of light by pigments used in the spectral filters of the LCD panels; absorption of light energy by the black-matrix used to spatially separate the subpixel filters in the LCD panel in order to enhance image contrast; and Fresnel losses due to the mismatching of refractive indices between layers within the LCD panels. As a result of such design factors, the light transmission efficiency of prior art color LCD panels is typically no more than 5%. Consequently, up to 95% of the light produced by the backlighting structure is converted into heat across the LCD panel. Thus, it is impossible to produce high brightness images from prior art color LCD panels used in either direct or projection display systems without using ultra-high intensity backlighting sources which require high power supplies, and produce great amounts of heat necessitating cooling measures and the like.

In response to the shortcomings and drawbacks of prior art color LCD

intensity modulating elements, for spectral filtering the intensity modulated light rays transmitted therethrough, to form a color image for either direct or projection viewing. Examples of such prior art LCD panel systems are described in "A Systems Approach to Color Filters for Flat-Panel Displays" by J. Hunninghake, et al, published in SID 94 DIGEST (pages 407-410), incorporated herein by reference.

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In response to the shortcomings and drawbacks of prior art color LCD

panel designs, several alternative approaches have been proposed in order to improve the light transmission efficiency of the panel and thus the brightness of images produced therefrom.

For example, US Patent No. 5,325,218 to Willett et al. discloses an LCD panel which uses tuned cholesteric liquid crystal (CLC) polarizers to replace absorptive dyed (neutral or dichroic) polarizers of prior art LCD panels to improve color purity, and a partial (i.e. local) light recycling scheme in order to improve the brightness of the LCD panel.

US Patent No. 5,418,631 to Tedesco also discloses an LCD panel which uses a holographic diffuser for directing light out from the light guiding panel of the backlighting panel structure, and CLC polarizers for locally recycling light diffused by the holographic diffuser in order to improve the brightness of the LCD panel.

US Patent No. 5,650,865 to Smith discloses a holographic backlight structure for an LCD panel, wherein a phase-retardation film layer is mounted on the first surface of a light pipe for the purpose of converting p-polarized light back into diffracted s-polarized light so that it is recycled (i.e. reused) by a hologram doublet (i.e. a reflection hologram and a transmission hologram) mounted on the opposite surface of the light pipe, thereby increasing the overall efficiency of the LCD panel assembly.

However, such prior art color LCD panel designs are not without shortcomings and drawbacks.

In particular, notwithstanding the use of non-absorptive CLC filters and localized light recycling principles, prior art LCD panels continue to require at least one light absorptive layer along the optical path extending from the backlighting structure to the viewer (i.e. along the light projection axis). Consequently, prior art LCD panels have very low

light transmission efficiencies. Thus the production of high brightness color images from prior art LCD panels has required high-intensity backlighting sources which consume great amounts of electrical power and produce high quantities of heat, and necessitate the use of fans and other cooling measures to maintain the temperature of both the LCD panel and the lamp(s) in the backlight structure within safe operating limits.

Thus, there is a great need in the art for an improved color LCD panel which is capable of producing high brightness color images without the shortcomings and drawbacks of the prior art LCD panel devices.

OBJECTS AND SUMMARY OF THE PRESENT INVENTION

Accordingly, a primary object of the present invention is to provide an improved color LCD panel capable of producing high brightness color images, while avoiding the shortcomings and drawbacks of prior art techniques.

Another object of the present invention is to provide such a color LCD panel, in which the spatial-intensity modulation and spectral (i.e. color) filtering functions associated with each and every subpixel structure of the LCD panel are carried out using systemic light recycling principles which virtually eliminate any and all absorption or dissipation of the spectral energy produced from the backlighting structure during color image production.

Another object of the present invention is to provide such a color LCD panel, in which image contrast enhancement is achieved through the strategic placement of broad-band absorptive-type polarization panels within the LCD panel.

Another object of the present invention is to provide such a color LCD

panel, in which glare due to ambient light is reduced through the strategic placement of a broad-band absorptive-type polarization panel within the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which a single polarization state of light is transmitted from the backlighting structure to the section of the LCD panel along the projection axis thereof, to those structure or subpanels where both spatial intensity and spectral filtering of the transmitted polarized light simultaneously occurs on a subpixel basis in a functionally integrated manner. At each subpixel location, spectral bands of light which are not transmitted to the display surface during spectral filtering, are reflected without absorption back along the projection axis into the backlighting structure where the polarized light is recycled with light energy being generated therewith. The recycled spectral components are then retransmitted from the backlighting structure into section of the LCD panel where spatial intensity modulation and spectral filtering of the retransmitted polarized light simultaneously reoccurs on a subpixel basis in a functionally integrated manner.

Another object of the present invention is to provide such a color LCD panel, in which the spatial-intensity modulation and spectral filtering functions associated with each and every subpixel structure of the LCD panel are carried out using the polarization/wavelength dependent transmission and reflection properties of CLC-based filters.

Another object of the present invention is to provide such a color LCD panel having a multi-layer construction with multiple optical interfaces, at which non-absorbing broad-band and pass-band (i.e. tuned) polarizing reflective panels are used to carryout systemic light recycling within the LCD panel such that light produced from the backlighting

structure is transmitted through the LCD panel with a light transmission efficiency of at least %90.

A further object of the present invention is to provide a novel LCD panel, in which both non-absorbing broad-band and pass-band (i.e. tuned) polarizer filters are used to avoid absorbing or dissipating any of the spectral energy produced from the backlighting structure during image production in order that high-brightness images can be produced using low-intensity backlighting structures.

Another object of the present invention is to provide such a color LCD panel, in which an array of pass-band CLC polarizing filter elements and an array of electrically-controlled liquid crystal elements are disposed between a pair of broad-band CLC polarizing filter panels used to realize the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the spectral components of light produced from the backlighting structure are recycled (i) between the spectral filtering array and the backlighting structure, (ii) within the backlighting structure itself, and (iii) among adjacent subpixels within the LCD panel in order to improve the overall light transmission efficiency of the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the array of liquid crystal elements can be realized using an array of electrically-controlled birefringent (ECB) elements which rotate the linear polarization state of the transmitted light, or invert the polarization state of circularly polarized light being transmitted through the LCD panel.

Another object of the present invention is to provide such a color LCD panel, in which the backlighting structure thereof can be realized using

a light guiding panel based on the principle of total internal reflection, a holographic diffuser based on the principle of refractive index matching and first order diffraction, or other suitable edge-lit backlighting structure which follows in general accordance with the physical principles of the present invention.

These and other objects of the present invention will become apparent hereinafter and in the Claims to Invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the Objects of the Present Invention, the following Detailed Description of the Illustrative Embodiments should be read in conjunction with the accompanying drawings, wherein:

Fig. 1A is a schematic representation of a direct-view type image display system in which the LCD panel of the present invention is employed;

Fig. 1B is a schematic representation of a projection-view type image display system in which the LCD panel of the present invention is employed;

Fig. 2 is an exploded schematic diagram of the first generalized LCD panel construction of the present invention, comprising (i) its backlighting structure realized by a quasi-specular reflector, a light guiding panel, a pair of edge-illuminating light sources, and broad-band polarizing reflective panel, (ii) its spatial-intensity modulating array realized as an array of electronically-controlled polarization direction rotating elements, and (iii) its array of spectral filtering elements realized as an array of pass-band polarizing reflective elements and a broad-band linearly polarizing reflective panel;

Fig. 2A is a perspective, partially broken away view of a portion of the LCD panel of Fig. 2, showing the electronically-controlled polarization rotating elements associated with a pixel structure thereof;

Fig. 2B is a perspective, partially broken away view of a portion of the LCD panel of Fig. 2, showing the novel construction of the spectral filtering elements associated with an exemplary pixel structure thereof, and the application of broad-band spectrally-tuned CLC film material over the light transmission portion of each subpixel region to achieve the required spectral filtering function thereof, and the application of broad-band reflective film material over the light blocking regions of each subpixel region on the backside thereof in order to maximize the light transmission efficiency of the LCD panel, and the application of broad-band absorptive film material over the light blocking region of each subpixel region on the front surface thereof in order to reduce glare at the surface of the LCD panel due to ambient light incident thereon;

Fig. 3A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a first particular embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 3A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the first particular embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-polarization rotating elements, and the pixel driver signals

provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 3B is a schematic representation graphically illustrating the reflection characteristics of the first broad-band linear polarizing (LP1) reflective panel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a broad-band linear polarizing panel responds to incident illuminating having linear polarization state LP1;

Fig. 3C is a schematic representation graphically illustrating the reflection characteristics of the second broad-band linear polarizing (LP1) reflective panel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a broad-band linear polarizing panel responds to incident illuminating having linear polarization state LP1;

Fig. 3D is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 3E is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 3F is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 3A1 and 3A2, indicating how such a non-absorbing

spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 4A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a second particular embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 4A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the second particular embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 4B is a schematic representation graphically illustrating the reflection characteristics of the broad-band left-handed circularly polarizing (LHCP) reflective panel of the LCD panel of Figs. 4A1 and 4A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having the circular polarization state LHCP;

Fig. 4C is a schematic representation graphically illustrating the reflection characteristics of the broad-band right handed circularly polarizing (RHCP) reflective panel of the LCD panel of Figs. 2, 4A1 and 4A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state RHCP;

Fig. 4D is a schematic representation graphically illustrating the

reflection characteristics of the pass-band left-handed circularly polarizing (LHCP) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 4A1 and 4A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having the left-handed circular polarization state LHCP;

Fig. 4E is a schematic representation graphically illustrating the reflection characteristics of the pass-band left handed circularly polarizing (LHCP) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 4A1 and 4A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having the left handed circular polarization state LHCP;

Fig. 4F is a schematic representation graphically illustrating the reflection characteristics of the pass-band left handed circularly polarizing (LHCP) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 4A1 and 4A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having the left handed circular polarization state LHCP;

Fig. 5 is schematic diagram of apparatus for use in manufacturing the LCD panel of the present invention;

Fig. 6 is schematic representation of an empirically determined function graphically illustrating the characteristic wavelength of CLC material used to make the pass-band circularly polarizing filter array of the illustrative embodiments, plotted as a function of the temperature at which the CLC material is exposed to ultra-violet radiation during manufacture;

Figs. 7A through 7C , taken together, provide a flow chart illustrating the steps undertaken during the preferred method of manufacturing the LCD panel;

Fig. 8 is an exploded schematic diagram of the second generalized LCD panel construction of the present invention comprising (i) its backlighting structure realized by a quasi-specular reflector, a light guiding panel, a pair of edge-illuminating light sources, and broad-band polarizing reflective panel, (ii) its array of spectral filtering elements realized as an array of pass-band polarizing reflective elements; and (iii) its spatial-intensity modulating array realized as an array of electronically-controlled polarization rotating elements and a broad-band polarizing reflective panel;

Fig. 8A is a perspective, partially broken away view of a portion of the LCD panel shown in Fig. 8, showing the electronically-controlled polarization rotating elements associated with a pixel structure thereof;

Fig. 9A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the LCD panel of Fig. 7, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 9A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the particular embodiment of the LCD panel shown in Fig. 8, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 9B is a schematic representation graphically illustrating the reflection characteristics of the broad-band linear polarizing (LP1) reflective panel of the LCD panel of Figs. 9A1 and 9A2, indicating how

such a broad-band linear polarizing panel responds to incident illuminating having linear polarization state LP1;

Fig. 9C is a schematic representation graphically illustrating the reflection characteristics of the absorptive broad-band linear polarizing (LP2) panel of the LCD panel of Figs. 9A1 and 9A2, indicating how such a broad-band linear polarizing panel responds to incident illuminating having linear polarization state LP2;

Fig. 9D is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 9A1 and 9A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 9E is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 9A1 and 9A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 9F is a schematic representation graphically illustrating the reflection characteristics of the pass-band linear polarizing (LP2) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 9A1 and 9A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having linear polarization state LP2;

Fig. 9A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a second particular embodiment of the LCD panel of Fig. 8, wherein the spatial-intensity

modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 10A1 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the LCD panel of Fig. 7, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "bright" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 10A2 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within the second particular embodiment of the LCD panel of Figs. 8, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, and the pixel driver signals provided thereto are selected to produce "dark" output levels at each of the RGB subpixels of the exemplary pixel structure;

Fig. 10B is a schematic representation graphically illustrating the reflection characteristics of the broad-band circularly polarizing (LHCP) reflective panel of the LCD panel of Figs. 10A1 and 10A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state LHCP;

Fig. 10C is a schematic representation graphically illustrating the reflection characteristics of the broad-band circularly polarizing (RHCP) reflective panel of the LCD panel of Figs. 10A1 and 10A2, indicating how such a broad-band circularly polarizing panel responds to incident illuminating having circular polarization state RHCP;

Fig. 10D is a schematic representation graphically illustrating the reflection characteristics of the pass-band circularly polarizing (RHCP) reflective filter element associated with each "blue" subpixel of the LCD panel of Figs. 10A1 and 10A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 10E is a schematic representation graphically illustrating the reflection characteristics of the pass-band circularly polarizing (RHCP) reflective filter element associated with each "green" subpixel of the LCD panel of Figs. 10A1 and 10A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 10F is a schematic representation graphically illustrating the reflection characteristics of the pass-band circular polarizing (RHCP) reflective filter element associated with each "red" subpixel of the LCD panel of Figs. 10A1 and 10A2, indicating how such a non-absorbing spectral filter element responds to incident broad-band illumination having circular polarization state RHCP;

Fig. 11 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a third embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "dark" output levels the red and blue subpixels of the exemplary pixel structure and a "bright" output level at the green subpixel level, and broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in images displayed

therefrom;

Fig. 12 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a fourth embodiment of the LCD panel shown in Fig. 2, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "dark" output levels at the red and blue subpixels of the exemplary pixel structure and a "bright" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom;

Fig. 13 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a third embodiment of the LCD panel shown in Fig. 8, wherein the spatial-intensity modulating elements of the LCD panel are realized using linear-type polarization rotating elements, the pixel driver signals provided thereto are selected to produce "bright" output levels the red and blue subpixels of the exemplary pixel structure and a "dark" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom;

Fig. 14 is a schematic representation of an exploded, cross-sectional view of an exemplary pixel structure within a fourth embodiment of the LCD panel shown in Fig. 8, wherein the spatial-intensity modulating elements of the LCD panel are realized using circular-type polarization rotating elements, the pixel driver signals provided thereto are selected

to produce "bright" output levels the red and blue subpixels of the exemplary pixel structure and a "dark" output level at the green subpixel level, and a broad-band absorptive linear polarizer is used in conjunction with each broad-band polarizing reflective panel in the LCD panel in order to provide improved image contrast in the images displayed therefrom; and

Fig. 15 is a schematic representation of a portable color image projection system in the form of a laptop computer, wherein a plurality of conventional backlighting structures are cascaded together and mounted to the rear portion of an LCD panel according to the present invention in order to provide an LCD panel assembly that can be mounted within the display portion of the system housing and project bright images onto a remote surface without the use of an external light source or a rear opening in the display portion of the housing, for projecting light therethrough during its projection-viewing mode of operation.

BEST MODES OF CARRYING OUT THE PRESENT INVENTION

Referring now to the figures in the accompanying Drawings, the illustrative embodiments of the present invention will now be described in detail, wherein like structures and elements shown within the figures are indicated with like reference numerals.

Overview of the LCD Image Display System of Present Invention

As shown in Fig. 1A, the LCD panel of the present invention is shown as part of a direct-view type color image display system 1 which is capable of supporting displaying high-resolution color images. During operation, the LCD panel 2 is actively driven by pixel driver circuitry 3

in response to color image data sets produced from a host system 4 which can be a computer-graphics board (subsystem), a video source (e.g. VCR), camera, or like system. The function of the LCD panel 2 is to spatial intensity modulate and spectrally filter on a subpixel basis the light emitted from an edge-illuminated backlighting structure 2A which may be realized in a variety of ways. The optically processed pattern of light forms color images at the surface of the LCD panel for direct viewing.

As shown in Fig. 1B, the LCD panel of the present invention 2' is shown as part of a projection-view type color image display system 1' which is capable of supporting displaying high-resolution color images. During operation, the LCD panel 2' is actively driven by pixel driver circuitry 3 in response to color image data sets produced from host system 4 which can be a computer-graphics board (subsystem), a video source (e.g. VCR), camera, or like system. The function of light source 5 is to produce and project a beam of light through the entire extent of the LCD panel. The function of the LCD panel is to spatial intensity modulate and spectrally filter the projected light on a subpixel basis. The optically processed pattern of light forms color images at the surface of the LCD panel which are then projected by projection optics 6 onto a remote display surface (e.g. screen or wall) for projection viewing.

The systems shown in Figs. 1A and 1B are each designed to support monoscopic viewing of color images representative of 2-D and/or 3-D geometry. However, these image display systems can be readily adapted to support stereoscopic viewing of 3-D objects and scenery of either a real and/or synthetic nature. One way of providing such viewing capablilties is to mount (i.e. laminate) a micropolarization panel

upon the display surface of the LCD panels 2 and 2' in order to display micropolarized spatially multiplexed images (SMIs) of 3-D objects and scenery, for viewing through electrically-passive polarizing eyeglasses, as disclosed in US Patent No. 5,537,144 and International Application Serial No. PCT/US97/03985, incorporated herein by reference.

In Fig. 2, the subcomponent structure of the first generalized embodiment of the LCD panel hereof is shown in great clarity. As shown, the first generalized embodiment of the LCD panel 2 comprises: a backlighting structure 7 including a quasi-diffusive reflector 7A, for producing a plane of broad-band light having a substantially uniform light intensity over the x and y coordinate axes thereof; a broad-band polarizing reflective panel 8; a pixelated array of polarization direction rotating elements 9 for spatial intensity modulation of light produced from the backlighting structure; a pixelated array of polarizing reflective spectral filter elements 10, for spectral filtering of light produced from the backlighting structure; and a broad-band polarizing reflective panel 11 for cooperative operation with the pixelated array of polarization direction rotating elements 9 and the pixelated array of polarizing reflective spectral filter elements 10. In an alternative embodiment, a broad-band absorptive-type panel can be substituted for broad-band polarizing reflective panel 11 in order to reduce glare due to ambient light incident upon the LCD panel during operation.

In order to produce high-resolution color images, the spatial period of the pixelated arrays 9 and 10 is selected to be relatively small in relation to the overall length and height dimensions of the LCD panel. In a conventional manner, each pixel structure in the LCD panel is comprised of a red subpixel 13A, a green subpixel 13B and blue subpixel 13C, as illustrated in Fig. 2A. As shown therein, each red

subpixel structure 13A comprises a red-band polarizing reflective spectral filtering element 10A which is spatially registered with a first polarization direction rotating element 9A. Each green subpixel structure 13B comprises a green-band polarizing reflective spectral filtering element 10B spatially registered with a second polarization direction rotating element 9B. Each blue subpixel element 13C comprises a blue-band polarizing reflective spectral filtering element 10C spatially registered with a third polarization direction rotating element 9C. The output intensity (i.e. brightness or darkness level) of each red subpixel structure is controlled by applying pulse-width modulated voltage signal V_R to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each green subpixel structure is controlled by applying pulse-width modulated voltage signal V_G to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each blue subpixel structure is controlled by providing pulse-width modulated voltage signal V_B applied to the electrodes of its electrically-controlled spatially intensity modulating element. By simply controlling the width of the above-described voltages V_R, V_G, V_B , the grey-scale intensity (i.e. brightness) level of each subpixel structure can be controlled in a manner well known in the LCD panel art.

<u>Overview of the First Generalized Embodiment of the LCD Panel Construction of the Present Invention</u>

In the first generalized LCD panel construction shown in Fig. 2, spectral filtering occurs after spatial intensity modulation. In the first illustrative embodiment of this LCD panel construction shown in Figs.

3A1 and 3A2, linear polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In the second illustrative embodiment of this LCD panel construction shown in Figs. 4A1 and 4A2, circular polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In each such illustrative embodiment, modifications will be made among the various components of the LCD panel shown in Fig. 2. Details regarding such modifications will be described hereinafter.

First Illustrative Embodiment Of the LCD Panel Construction of Fig. 2

In the illustrative embodiments shown in Figs. 3A1 and 3A2, the backlighting structure 7 is realized by quasi-diffusive reflector 7A, a light guiding panel 7B, a pair of edge-illuminating light sources 7C1 and 7C2 , and a pair of focusing mirrors 7D1 and 7D2, respectively, for coupling light produced by light sources 7C1 and 7C2 into the edges of light guiding panel 7B. Preferably, the light guiding panel 7B is made from an optically transparent substrate such as Plexiglass® acrylic, and light sources 7C1 and 7C2 are realized by a pair of miniature fluorescent tubes which produce unpolarized light.

During backlight operation, light produced by sources 7C1 and 7C2 is coupled with the help of reflectors 7D1 and 7D2 into the edges of the light guiding panel 7B where it is totally internally reflected in a conventional manner. In the illustrative embodiment, the front surface of the light guiding panel 7B bears very fine pits in order to create optical conditions at the surface thereof which destroys conditions for total internal reflection and allows light to leak out in the direction of the array of spatial intensity modulating elements. Understandably,

there are many alternative techniques for producing a plane of unpolarized light that can be used in the construction of any particular embodiment of the LCD panel of the present invention.

For purposes of illustration only, the spectral filtering function realized within each LCD panel of the illustrative embodiments is based on the RGB (red, green, blue) additive primary color system. Alternatively, however, the spectral filtering function within each LCD panel may be based on the CMY (cyan, magenta, yellow) subtractive primary color system.

In the illustrative embodiments of the LCD panel hereof, the emission spectrum of the light source within the backlighting panel is assumed to be "white", and the spectral filtering function of the LCD panel is based on the RGB color system. Thus, each polarizing reflective spectral filter element 10A, 10B, 10C is designed to have "pass-band" characteristics so that all of the spectral content of the red, green and blue bands of the light source are used to produce color images for display. In such illustrative embodiments, each polarizing reflective spectral filter element 10A, 10B and 10C is realized as a "pass-band" polarizing reflective spectral filter element.

However, in other embodiments of the LCD panel hereof, the light source within its backlighting structure may emit a "narrow-band" spectra over the red, green and blue bands of the optical spectrum. In such alternative embodiments of the LCD panel, the pixelated array of polarizing reflective spectral filter elements can be tailored to overlap the RGB emission spectra. In such alternative embodiments, each polarizing reflective spectral filter element 10A, 10B and 10C can be realized as a "narrow-band" polarizing reflective spectral filter element.

In the illustrative embodiment of Figs. 3A1 and 3A2, the broad-band

linear polarizing reflective panel 8' has a characteristic linear polarization state LP1 which serves as a polarization reference. Similarly, broad-band linear polarizing reflective panel 11' has a characteristic linear polarization state LP1. The reflection characteristics of the broad-band linearly polarizing reflective panel 8' are graphically illustrated in Fig. 3B for incident light having linear polarization state LP1, whereas the reflection characteristics of the broad-band linearly polarizing reflective panel 11' are graphically illustrated in Fig. 3C for incident light having linear polarization state LP1. For incident light having orthogonal linear polarization state LP2, the broad-band transmission characteristics for these panels are substantially uniform for all wavelengths over the optical band.

In the illustrative embodiments of the LCD panel hereof, each "pass-band" polarizing reflective spectral filter element in pixelated array 10' and broad-band polarizing reflective panels 8' and 11' are realized using cholesteric liquid crystal (CLC) material of the type disclosed in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material" published under International Publication Number WO 97/16762, incorporated herein by reference in its entirety. The polarizing reflective properties of such CLC material is described in detail in Applicant's US Patent No. 5,221,982, incorporated herein by reference.

A preferred method of making the broad-band circularly polarizing reflective panels 8' and 11' is disclosed in great detail in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra. An alternative method of making broad-band linearly polarizing reflective panels 8' and 11' is disclosed in EPO Application No. 94200026.6 entitled "Cholesteric Polarizer and

Manufacture Thereof", incorporated herein by reference.

In the illustrative embodiment of Figs. 3A1 and 3A2, the polarization rotating array 9 is realized as an array of electronically-controlled linear polarization rotating elements 9' for rotating the linearly polarized electric field along LP1 to the LP2 polarization direction as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 3A1 and 3A2, each electronically-controlled linear polarization rotating element can be realized as a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by a control voltage well known in the art. To construct the linear polarization rotating elements, thin film transistors (TFTs) can be used to create the necessary voltages across a layer of liquid crystal material to achieve alignment of the liquid crystal molecules and thus cause the corresponding element to not rotate the polarization direction of transmitted light passing therethrough. In its electrically-inactive state (i.e. no voltage is applied), the electric field intensity of light exiting from the cell is substantially zero and thus a "dark" subpixel level is produced. In its electrically-active state (i.e. the threshold voltage V_T is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 3A1 and 3A2, the pixelated array of spectral filtering elements 10 is realized as an array of pass-band linear polarizing reflective elements 10' formed within a single plane. Broad-band linearly polarizing reflective panel 11' is laminated to the pixelated array of spectral filtering elements 10. As indicated in Figs. 3A1 and 3A2, each pass-band linear polarizing reflective element

in the pixelated pass-band linear polarizing panel 10' has a LP2 characteristic polarization state, whereas the broad-band linear polarizing reflective panel has an LP1 characteristic polarization state.

As shown in Fig. 3D, each pass-band polarizing reflective element associated with a "blue" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the red reflective band $\Delta\lambda_R$, whereas all spectral components having the LP2 characteristic polarization state or a wavelength within the blue reflective band $\Delta\lambda_B$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band polarizing reflective element 10C' associated with each "blue" subpixel is "tuned" will be described hereinafter with reference to the method of LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

As shown in Fig. 3E, each pass-band polarizing reflective element associated with a "green" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the red reflective band $\Delta\lambda_R$ or the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the LP2 characteristic polarization state or a wavelength within the green reflective band $\Delta\lambda_G$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band polarizing reflective element 10B' associated with each "green" subpixel is "tuned" will be described hereinafter with reference to the method of

LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

As shown in Fig. 3F, each pass-band polarizing reflective element associated with a "red" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the LP1 characteristic polarization state or a wavelength within the red reflective band $\Delta\lambda_R$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band polarizing reflective element 10A' associated with each "red" subpixel is "tuned" will be described hereinafter with reference to the method of LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

In the above description of the first illustrative embodiment of the LCD panel construction of Fig. 2 has assumed that the complete surface area associated with each subpixel region is available for light intensity modulation and spectral filtering functions. In practice, however, this is not the case. As shown in Fig. 2B, each subpixel region of the LCD panel includes (i) a light transmission region (i.e. aperture region) 50 in which pass-band linear polarizing reflective element is located, and a light blocking region (i.e. stop portion) 51 in which TFTs, wires, etc. are located. Typically, the light blocking region occupies a significant percentage of the subpixel surface area (e.g. 30-50 percent of the total pubpixel area). As discussed in detail above, the application of broad-band spectrally-tuned CLC film material 52R, 52G and 52B over the light transmission portion of each RGB subpixel region is to achieve the required spectral filtering function thereof.

In order to maximize the light transmission efficiency of the LCD panel, broad-band reflective film material (e.g. broad-band reflector film) 53 is applied over the light blocking region 51 of each subpixel region on the backside thereof. In the first illustrative embodiment described above, a pattern of broad-band reflector film, corresponding to the light blocking portions of the subpixel regions, can be applied to the back surface of the broad-band polarizing reflective panel 8' (facing the backlighting structure) in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask between the backlighting panel and the pixelated spatially intensity modulation panel 8'. This prevents the absorption and scattering of produced light at structures associated with the light blocking portion of the subpixels of the LCD panel.

In order to reduce glare at the surface of the LCD panel due to ambient light incident thereon, a broad-band absorptive film material (e.g. carbonized polymer film) 54 is applied over the light blocking region 51 of each subpixel region on the front surface thereof. In the first illustrative embodiment described above, a pattern of broad-band absorption film, corresponding to the light blocking portions of the subpixel regions, can be applied to the rear surface of the pixelated spectral filtering panel 10' in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask between the viewer panel and the pixelated spatially intensity modulation panel 8'. This prevents reflection and scattering of ambient light off structures associated with the light blocking portion of the subpixels of the LCD panel, and thus reduces glare at the surface of the LCD panel due to ambient light incident thereon.

Second Illustrative Embodiment Of the LCD Panel Construction of Fig. 2

In the illustrative embodiment of the LCD panel shown in Figs. 4A1 and 4A2, the backlighting structure 7 is realized in a manner described above. The broad-band linear polarizing reflective panel 8'' has a characteristic circular polarization state LHCP (i.e. Left Hand Circular Polarization) which serves as a polarization reference. Broad-band circular polarizing reflective panel 11'' has a characteristic circular polarization state RHCP (i.e. Right Hand Circular Polarization) which is orthogonal to LHCP. A preferred method of making the broad-band circularly polarizing reflective panels 8''' and 11''' is disclosed in great detail in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra. An alternative method of making broad-band circularly polarizing reflective panels 8'' and 11'' is disclosed in EPO Application No. 94200026.6 entitled "Cholesteric Polarizer and Manufacture Thereof", incorporated herein by reference. The reflection characteristics of the broad-band circularly polarizing reflective panel 8'' are graphically illustrated in Fig. 4B for incident light having circular polarization state LHCP, whereas the reflection characteristics of the broad-band circularly polarizing reflective panel 11'' are graphically illustrated in Fig. 4C for incident light having circular polarization state RHCP.

In the illustrative embodiment of Figs. 4A1 and 4A2, the pixelated polarization rotating array 9 is realized as an array of electronically-controlled circular polarization rotating elements 9'' for rotating the circularly polarized electric field along the LHCP direction to the RHCP direction (or vice versa) as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 4A1 and 4A2, each electronically-controlled

circular polarization rotating element 9A'', 9B'', 9C'' can be realized as a π-cell, whose operation is by controlled by a control voltage well known in the art. In its electrically-inactive state (i.e. no-voltage is applied), the electric field intensity of light exiting from the cell is substantially zero, thus a "dark" subpixel level is produced. In its electrically-active state (i.e. the threshold voltage V_T is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 4A1 and 4A2, the array of spectral filtering elements 10 is realized as a pixelated array of pass-band circular polarizing reflective elements 10'' formed within a single plane. Broad-band circularly polarizing reflective panel 11'' is laminated to the pixelated array of pass-band circular polarizing reflective elements 10''. As indicated in Figs. 4A1 and A2, each pass-band circular polarizing reflective element in the pixelated pass-band circular polarizing panel 10'' has a LHCP characteristic polarization state, whereas the broad-band circular polarizing reflective panel 8'' adjacent the backlighting structure has an LHCP characteristic polarization state, and broad-band circular polarizing reflective panel 10'' has a RHCP characteristic polarization state, indicated in Figs. 4B and 4C.

As shown in Fig. 4D, each pass-band polarizing reflective element 10C'' associated with a "blue" subpixel in the pixelated pass-band linear polarizing panel 10C'' is particularly designed to reflect nearly 100% all spectral components having the LHCP characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the red reflective band $\Delta\lambda_R$, whereas all spectral components having the LHCP characteristic polarization state or a wavelength within the blue

reflective band $\Delta\lambda_B$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band polarizing reflective element associated with each "blue" subpixel is "tuned" will be described hereinafter with reference to the method of LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

As shown in Fig. 4E, each pass-band polarizing reflective element [redacted] linear polarizing panel 10'' is particularly designed to reflect nearly 100% all spectral components having the LHCP characteristic polarization state and a wavelength within the red reflective band $\Delta\lambda_R$ or the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the LHCP characteristic polarization state or a wavelength within the green reflective band $\Delta\lambda_G$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band polarizing reflective element associated with each "green" subpixel is "tuned" will be described hereinafter with reference to the method of LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

As shown in Fig. 4F, each pass-band polarizing reflective element 10A'' associated with a "red" subpixel in the pixelated pass-band linear polarizing panel 10'' is particularly designed to reflect nearly 100% all spectral components having the LHCP characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the LHCP characteristic polarization state or a wavelength within the red reflective band $\Delta\lambda_R$ are transmitted nearly 100% through the pass-band polarizing reflective element. The manner in which the pass-band

polarizing reflective element associated with each "red" subpixel is "tuned" will be described hereinafter with reference to the method of LCD panel fabrication illustrated in Figs. 5, 6, 7A through 7C.

Notably, the above description of the second illustrative embodiment of LCD panel construction of Fig. 2 has assumed that the complete surface area associated with each subpixel region is available for light intensity modulation and spectral filtering functions. In practice, however, each subpixel region of the LCD panel includes (i) a light transmission region (i.e. aperture region) 50 in which pass-band linear polarizing reflective element is located, and a light blocking region (i.e. stop portion) 51 in which TFTs, wires, etc. are located.

In order to maximize the light transmission efficiency of the LCD panel, broad-band reflective film material (e.g. broad-band reflector film) 53 is applied over the light blocking region 51 of each subpixel region on the backside thereof. In the first illustrative embodiment described above, a pattern of broad-band reflector film, corresponding to the light blocking portions of the subpixel regions, can be applied to the back surface of the broad-band polarizing reflective panel 8'' (facing the backlighting structure) in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask between the backlighting panel and the pixelated spatially intensity modulation panel 8''. This prevents the absorption and scattering of produced light from structures associated with the light blocking portion of the subpixels of the LCD panel.

In order to reduce glare at the surface of the LCD panel due to ambient light incident thereon, a broad-band absorptive film material (e.g. carbonized polymer film) 54 is applied over the light blocking region 51 of each subpixel region on the front surface thereof. In the

first illustrative embodiment described above, a pattern of broad-band absorption film, corresponding to the light blocking portions of the subpixel regions, can be applied to the rear surface of the pixelated spectral filtering panel 10'' in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask between the viewer panel and the pixelated spatially intensity modulation panel 8''. This prevents reflection and scattering of ambient light off structures associated with the light blocking portion of the subpixels of the LCD panel, and thus reduces glare at the surface of the LCD panel due to ambient light incident thereon.

SYSTEMIC LIGHT RECYCLING WITHIN THE LCD PANEL OF THE PRESENT INVENTION

The light transmission efficiency of prior art LCD panels has been severely degraded as a result of the following factors: absorption of light energy due to absorption-type polarizers used in the LCD panels; absorption of light reflected off thin-film transistors (TFTs) and wiring of the pixelated spatial intensity modulation arrays used in the LCD panels; absorption of light by pigments used in the spectral filters of the LCD panels; absorption of light energy by the black-matrix used to spatially separate the subpixel filters in the LCD panel in order to enhance image contrast; and Fresnel losses due to the mismatching of refractive indices between layers within the LCD panels. As a result of such light energy losses, it has been virtually impossible to improve the light transmission efficiency of prior art LCD panels beyond about 5%.

The LCD panel of the present invention overcomes each of the above drawbacks by employing a novel scheme of "systemic light recycling" which operates at all levels of the LCD system in order to avoid the light

energy losses associated with prior art LCD panel designs, and thereby fully utilize nearly 100% of the light energy produced by the backlighting structure thereof. While the details of this novel systemic light recycling scheme will be hereinafter described for each of the illustrative embodiments, it will be appropriate at this juncture to briefly set forth the principles of this systemic light recycling scheme.

In each of the embodiments of the present invention, a single polarization state of light is transmitted from the backlighting structure to those structures (or subpanels) of the LCD panel where spatial intensity modulation and spectral filtering function of the transmitted polarized light simultaneously occurs on a subpixel basis and in a functionally integrated manner. At each subpixel location, spectral bands of light which are not transmitted to the display surface during spectral filtering are reflected without absorption back along the projection axis into the backlighting structure where the polarized light is recycled with light energy being generated therewith and then retransmitted from the backlighting structure into section of the LCD panel where spatial intensity modulation and spectral filtering of the retransmitted polarized light simultaneously occurs on a subpixel basis in a functionally integrated manner. At each subcomponent level within the LCD panel, spectral components of transmitted polarized light which are not used at any particular subpixel structure location are effectively reflected either directly or indirectly back into the backlighting structure for recycling with other spectral components for retransmission through the backlighting structure at the operative polarization state, for reuse by both the same and neighboring subpixel structures. The mechanics of this novel systemic light recycling scheme are schematically illustrated in Figs. 3A1,3A2, 4A1, 4A2, 9A1, 9A2, 11,

12, 13 and 14, and will be described in greater detail hereinafter. By virtue of this novel systemic light recycling scheme of the present invention, it is now possible to design and construct LCD panels that can utilize produced backlight with nearly 100% light transmission efficiency, in marked contrast with prior art LCD panels having efficiencies of about 5%.

Apparatus For Fabricating The LCD Panels Hereof

Fig. 5 provides a schematic representation of a computer-controlled system 15 which can be used during the fabrication of the pixelated pass-band (linear or circular) polarizing reflective panels 10' and 10'' hereof. As shown, the computer-controlled system 15 comprises a number of subcomponents, namely: a fixture 16 for supporting a plate 17 the size of the LCD panel to be fabricated, within the x-y plane of a coordinate reference frame embedded within the system; coating means 18 (e.g. applicator technology) for coating one surface of the plate with a CLC mixture 19 containing in its liquid phase, liquid crystals, monomers, and other additives; a temperature-controlled oven 20 (with a UV transparent window), within which the CLC coated plate 17 can be transported and maintained for optical and thermal processing; a subpixel-exposure mask 21 having a pattern of apertures 21A, 21B and 21C which spatially correspond with the red, green or blue subpixel structures, respectively, of the LCD panel to be fabricated; a subpixel-array mask 21' having a pattern of opaque subpixel regions which spatially correspond with thc red, green or blue subpixel structures formed on the CLC-coated plate of the LCD panel to be fabricated; a mask translator 22 for precisely translating the masks 21 and 21' relative to the fixture along the x and y axes of the system; a source of

ultraviolet (UV) radiation 23 for producing a focused beam of UV radiation having a specified bandwidth, for exposing the layer of CLC material 19 upon the plate supported within the fixture, while the CLC layer is precisely maintained at a preselected temperature; a temperature controller 24 for controlling the temperature of the interior of the oven 20 and thus the layer of CLC material coated on the plate; and a system controller 25 for controlling the operation of the mask translator 22 and temperature controller 24 during the fabrication process.

The primary function of this system 15 is to control the temperature of the CLC coated plate 17 and its UV exposure at each of the three subpixel filter fabrication stages involved in the fabrication of panel 10. In particular, during the "red" subpixel processing stage, the mask 21 is translated relative to the CLC coated plate 17 so allow produced UV radiation to expose only the red subpixel regions on the CLC coated plate, while the CLC coating is maintained at temperature T_R, determined from the characteristic shown in Fig. 6. During the "green" subpixel processing stage, the mask 21 is translated relative to the CLC coated plate 17 so allow produced UV radiation to expose only the green subpixel regions on the CLC coated plate 17, while the CLC coating is maintained at temperature T_G, determined from the characteristic shown in Fig. 6. During the "blue" subpixel processing stage, the mask is translated relative to the CLC coated plate so allow produced UV radiation to expose only the red subpixel regions on the CLC coated plate, while the CLC coating is maintained at temperature T_R, determined from the characteristic shown in Fig. 6. During the "pixel matrix" processing stage, mask 21 is removed and mask 21' positioned relative to the CLC-coated plate so allow produced UV radiation to

expose at the required UV-light intensity I_{BB}, only the subpixel intersticial regions on the CLC coated plate, while the CLC coating is maintained at temperature T_{BB}, determined from the characteristics and properties of the CLC mixture used.

For each RHLP or LHCP CLC mixture to be used to make the pixelated pass-band circularly polarizing reflective panel 10 , the graphical plot of Fig. 6 is empirally acquired by analytical procedures well known in the CLC art. Having acquired this wavelength versus UV-exposure temperature plot for any given CLC mixture, the LCD panel designer can easily determine: (1) the UV-exposure temperature required in order to tune the subpixel filters to transmit only over the narrow "red" spectral pass-band $\Delta\lambda_R$, while reflecting all other wavelengths without energy loss or absorption; (2) the UV-exposure temperature required in order to tune the subpixel filters to transmit only over the narrow "green" spectral pass-band $\Delta\lambda_G$, while reflecting all other wavelengths without energy loss or absorption; and (3) the UV-exposure temperature required in order to tune the subpixel filters to transmit only over the narrow "blue" spectral pass-band $\Delta\lambda_B$, while reflecting all other wavelengths without energy loss or absorption.

Method Of Fabricating The LCD Panels Hereof

Referring now to Figs. 7A through 7C, a preferred fabrication method will now be described for the LCD panel illustrated in Figs. 2, 3A1 and 3A2.

As indicated at Block A of Fig. 7A, the first step of the fabrication method involves applying a layer of the selected CLC-mixture onto the surface of an optically-transparent support substrate (e.g. glass plate)

having length and width dimensions equal to the size of the LCD panel to bc fabricated. Methods for selecting and mixing the CLC components of the CLC mixture are described in: International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra; the SID publication entitled "Cholesteric Reflectors with a Color Pattern" by R. Maurer, F-H Kreuzer and J. Stohrer published at pages 399-402 of SID 94 DIGEST (1994); and the SID publication entitled "Polarizing Color Filters Made From Cholesteric LC Silicones" by Robert Maurer, Dirk Andrejewski, Franz-Heinrich Kreuzer, and Alfred Miller, at pages 110-113 of SID 90 DIGEST (1990); each said document both incorporated herein by reference in its entirety.

At Block B in Fig. 7A, the CLC-coated plate 17 is loaded into the oven shown in Fig. 5 which is operated to maintain its temperature at T_B indicated in Fig. 6. As indicated in Block C, the mask 21 is translated into position over the CLC-coated plate 17 for exposure to UV radiation to form an array of pass-band polarizing reflective elements tuned to the blue spectral-band $\Delta\lambda_B$. Then at Block D, the CLC-coated plate 17 is exposed to UV light through the mask positioned for forming pass-band polarizing reflective elements tuned to the blue spectral-band $\Delta\lambda_B$.

At Block E, the mask 21 is translated into position over the CLC-coated plate 17 for exposure to UV radiation to form an array of pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$. Then at Block F, the oven temperature T_G is selected and the CLC coated plate is allowed to reach this temperature. At Block , the CLC-coated plate 17 is exposed to UV light through the mask positioned for forming pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$.

At Block H, the mask 21 is translated into position over the CLC-coated plate 17 for exposure to UV radiation to form an array of pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$. Then at Block I, the oven temperature is T_R is selected and the CLC coated plate is allowed to reach this temperature. At Block in Fig. 7A, the CLC-coated plate is exposed to UV light through the mask positioned for forming pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$.

At Block K in Fig. 7B, the subpixel-exposure mask 21 is removed and the pixel-array mask 21' installed above the CLC-coated plate. Then at Block L, the oven temperature is adjusted to T_{BB} and the CLC-coated plate allowed to attain this temperature. Temperature T_{BB} can be determined in accordance with the teaching disclosed in Applicant's International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra, so that broad-band polarizing reflection characteristics will be imparted to the CLC-coating over those unprotected regions determined by mask 21'. At Block M, the intensity of the UV light is set to the value I_{BB} required to achieve broad-band operation using the particular CLC-mixture at exposure temperature T_{BB}. Similarly, light intensity I_{BB} can be determined in accordance with the teaching disclosed in Applicant's International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra. Then at Block N the CLC-coated plate is exposed to the UV light at intensity I_{BB} and temperature T_{BB} to form a broad-band polarizing reflective region between the interstices of the subpixel filter elements formed on the CLC-coated plate. Notably, this patterned reflective region will be designed to reflect from the

subpixel interstices, polarized light transmitted from the backlighting structure so that it can be recycled (i.e. reused) in accordance with the principles of the present invention. At Block O, the exposed CLC-coated plate is removed from the oven and allowed to cool to room temperature. In the particular embodiments of Figs. 3A1,3A2, 4A1,4A2, 11, and 12, the broad-band absorptive-type polarization pattern described above in connection with Fig. 2B can be formed on the front surface of the exposed/cured CLC-coated plate, for absorbing broad-band light falling incident upon the light blocking portions of each subpixel region of the LCD panel, thereby reducing glare and improving image contrast. In the particular embodiments of Figs. 9A1,9A2, 10A1,10A2, 13, and 14, the broad-band light reflecting pattern described above in connection with Fig. 2B can be formed on the back surface of the exposed/cured CLC-coated plate, for reflecting produced light (from the backlighting structure) falling incident upon the light blocking portions of each subpixel region of the LCD panel, thereby optimizing light recycling at the spectral filtering panel in the system.

At this stage, a CLC panel is provided having formed therein, three spatially arranged arrays of pass-band circularly-polarizing reflective elements (i.e. subpixel spectral filter elements) along a single plane with a polarizing reflective matrix-mask region formed therebetween for improving image contrast while systemically recycling polarized light which does not contribute to the formation of image structure. Each array of pass-band circularly-polarizing reflective elements is adapted for use in the LCD panel embodiments of Figs. 4A1 and 4A2. The first array is tuned to reflect only RH (or LH) circularly polarized spectral components having a wavelength in the red spectral-band $\Delta\lambda_R$; the second array is tuned to reflect only RH (or LH) circularly polarized

spectral components having a wavelength in the green spectral-band $\Delta\lambda_G$; and the third array is tuned to reflect only RH (or LH) circularly polarized spectral components having a wavelength in the blue spectral-band $\Delta\lambda_B$. As indicated at Block P in Fig. 7B, in order that each one of these subpixel filter elements reflects linearly polarized light as required in the LCD panel embodiments of Figs. 3A1 and 3A2, 9A1 and 9A2, 11 and 13 , rather than circularly polarized light, it is necessary to impart a $\pi/2$ (i.e. quarter-wave) phase retardation region (or structure) to each one of these elements in order to impart a linear polarization state thereto. Such circular-to-linear polarization conversion can be achieved by laminating onto the spatially-arranged arrays of pass-band circularly-polarizing reflective elements (i.e. subpixel filter elements), a first quarter-wave phase retardation panel patterned according to the composite subpixel pattern of the spectral filtering array. This will fabrication step will effectively convert the circular polarization state of each spectral filter element in the polarizing reflective spectral filtering array to the appropriate linear polarization state called for by the LCD panel design under construction. Similarly, a second quarter-wave phase retardation panel, patterned according to the subpixel interstice pattern, can be appropriately laminated onto the first quarter-wave pattern, in order to convert the circular polarization state of the circularly polarizing reflective subpixel interstice pattern to the appropriate linear polarization state called for by the LCD panel design under construction. An excellent tutorial and overview on the polarization-reflective properties of CLC materials and principles of polarization state conversion (i.e. linear-to-circular, circular-to-linear, linear-to-linear, circular-to-circular, unpolarized-to-linear, and unpolarized-to-circular) can be found in Applicant's US

Patent No. 5,221,982, incorporated herein by reference. At the end of this stage of the fabrication method, the result is an array of linearly-polarized reflective elements tuned to the particular spectral band.

In the event that LCD panels of the type shown in Figs. 3A1 and 3A2, 9A1 and 9A2, 11 and 13 are being constructed (rather than the LCD panels of Figs. 4A1 and 4A2, 10A1 and 10A2, 12 and 14), it will be necessary to use linear, rather than circular, polarization principles therein. In such cases, it will be necessary to realize a pixelated array of "linear polarization" rotating elements, rather than a pixelated array of circular polarization rotating elements (i.e. an array of π-cells) as a subcomponent of the LCD panel system. For purposes of illustration, however, the balance of the description of the fabrication method hereof will be directed to the fabrication of the LCD panel of Figs. 3A1 and 3A2. It will be understood, however, that to fabricate an LCD panel using circular polarization rotating elements (i.e. an array of π-cells), the illustrative fabrication method will be modified in ways which involve the fabrication of an array of circular polarization rotating elements in a manner well known in the art.

At Block Q in Fig. 7B, an ITO layer is applied to the surface of the CLC-coated panel 17 produced above. Then at Block R of Fig. 7C, a polyamide alignment layer is applied to the ITO layer. At Block S in Fig. 7C, a patterned layer of ITO is applied to the surface of a second glass plate the same size as the glass plate supporting the CLC-layer. The pattern of ITO material corresponds to the composite subpixel pattern of the pixelated spectral filter array fabricated above. Then at Block T, a layer of liquid crystal (LC) material of a prespecified thickness is applied to the previously applied polyamide layer.

At Block U of Fig. 7C, the ITO layer on the second glass plate is

brought into physical contact with the LC layer in order to construct a twisted nematic (TN) or super-twisted nematic (STN) array with a spectral filtering array formed thereon. Then at Block V, electrically conductive electrodes are attached to the patterned ITO layer in a conventional manner.

At Block in Fig. 7C, the first broad-band linear polarizing reflector panel 8'' (prefabricated) is attached to the second surface of the second optically transparent plate. At Block , the second broad-band linear polarizing reflector panel 11' (prefabricated) is attached to the second surface of the first optically transparent plate on which the spectral filtering array has been previously formed during the fabrication method. Then at Block Y, the first broad-band linear polarizing reflector panel (prefabricated) 8' is mounted to the backlighting structure being used. In the illustrative embodiments, this step involves mounting the first broad-band linear polarizing reflector panel to the light guiding panel 7B of the backlighting structure 7, providing a slight air gap between the interfaced optical surfaces. The quasi-diffusive reflector 7A associated with the backlighting structure can be directly mounted on the rear surface of the light guiding panel, as illustrated in Figs. 2 and 3A1 and 3A2.

Upon completing the steps of the above-described fabrication process, the LCD panel shown in Figs. 3A1 and 3A2 is provided. Manufacture of the LCD panel shown in Figs. 4A1 and 4A2 can be carried out much in the same way as described above with one minor exception. As circularly polarizing reflective panels are used in this particular embodiment, there is no need to impart a quarter-wave phase retardation to the pass-band circularly polarizing reflective elements 9A, 9B 9C. Also, the broad-band circularly polarizing

reflective panels 8'' and 11'', rather than panels 8' and 11', are used to construct the LCD panel of the present invention.

While the above described method has described forming the pixelated array of pass-band polarizing reflecting elements within a single layer of CLC material, it may be desirable in particular applications to make this pixelated reflective filtering array by using alternative fabrication techniques including photolithography, screen-printing, gravure printing and other methods known in the art. When using such alternative techniques, a pixelated polarizing reflective array of subpixel filter elements can be separately fabricated for each spectral band (e.g. red, green and blue) to provide three panels each embodying a subpixel filtering array tuned to a particular band along the optical spectrum. These subpixel spectral filter arrays can then be aligned in proper registration and bonded together through laminatation techniques to form a composite structure having pass-band polarizing-reflective properties similar to those exhibited by the pixelated passed-band reflecting filter array of unitary construction described above.

Operation Of The First And Second Illustrative Embodiments of the LCD Panel of the First Generalized Embodiment of the Present Invention

Having described in detail how to make the LCD panels illustrated in Figs. 2, 3A1, 3A2, and 4A1 and 4A2, it is appropriate at this juncture to now describe their operation with reference to the exemplary pixel structure detailed in such figure drawings.

As shown in Figs. 3A1 and 3A2, unpolarized light is produced within the backlighting structure and is composed of spectral components having both LP1 and LP2 polarization states. Only spectral components having the LP2 polarization state are transmitted through the broad-

band linear polarizing reflective panel 8' adjacent the backlighting panel 7, whereas spectral components having polarization state LP1 incident thereon are reflected therefrom without energy loss or absorption. Spectral components reflecting off broad-band linear polarizing reflective panel 8' on the backlighting structure side strike quasi-diffusive reflector 7A, and undergo a polarization inversion (LP1 to LP2). This reflection process occurs independent of wavelength. The spectral components which were inverted from LP1 to LP2 having the LP2 polarization state are transmitted through the broad-band linear polarizing reflective panel 8' adjacent the backlighting structure.

When a linear polarization rotating element 10A, 10B and 10C associated with a red, green or blue subpixel is driven into its inactive-state as shown in Fig. 3A1, the polarization rotating element associated therewith transmits the spectral components therethrough independent of wavelength while effecting an orthogonal conversion in polarization state (i.e. LP1 to LP2 and LP2 to LP1) and producing a "dark" subpixel level in response to the inactive-state into which it has been driven.

When a "red" subpixel is driven into its "dark" state shown in Fig. 3A1, spectral components within the backlighting panel having wavelengths within the "red" , "green" or "blue" band $\Delta\lambda_R$ and polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linearly polarizing reflective panel 8', the "red" pass-band linearly polarizing reflective element 10A' and reflect off broad-band linearly polarizing reflective panel 11' without absorption. The reflected "red", "green" and "blue" spectral components with the LP2 polarization state (i.e. λ_R^{LP2}, λ_G^{LP2}, λ_B^{LP2}) are retransmitted through pass-band linearly polarizing reflective element 10A', linear polarization rotating element

9A' , and broad-band linearly polarizing reflective panel 8' back into the backlighting structure for systemic recycling .

When a "green" subpixel is driven into its "dark" state shown in Fig. 3A1, spectral components within the backlighting panel having wavelengths within the "red" , "green" or "blue" band $\Delta\lambda_R$ and polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linearly polarizing reflective panel 8' and the "green" pass-band linearly polarizing reflective element 10B' and then reflect off broad-band linearly polarizing reflective panel 11' without absorption. These reflected "red", "green" and "blue" spectral components with the LP2 polarization state (i.e. λ_R^{LP2}, λ_G^{LP2}, λ_B^{LP2}) are retransmitted through pass-band linearly polarizing reflective element 10B', linear polarization rotating element 9B' , and broad-band linearly polarizing reflective panel 8' back into the backlighting structure for systemic recycling .

When a "blue" subpixel is driven into a "dark" state shown in Fig. 3A1, spectral components within the backlighting panel having wavelengths within the "red" , "green" or "blue" band $\Delta\lambda_R$ and polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linearly polarizing reflective panel 8' and the "blue" pass-band linearly polarizing reflective element 10C' and then reflect off broad-band linearly polarizing reflective panel 11' without absorption. These reflected "red", "green" and "blue" spectral components with the LP2 polarization state (i.e. λ_R^{LP2}, λ_G^{LP2}, λ_B^{LP2}) are retransmitted through pass-band linearly polarizing reflective element 10C', linear polarization rotating element 9C' , and broad-band linearly polarizing reflective panel 8' back into the backlighting structure for systemic recycling.

When a linear polarization rotating element is controlled in its

active-state as shown in Fig. 3A2, the element transmits the spectral components therethrough independent of wavelength without effecting a conversion in polarization state, producing a "bright" subpixel level in response to the active-state into which it has been driven.

When a "red" subpixel is driven into its "bright" state as shown in Fig. 3A2, spectral components within the backlighting panel having wavelengths within the "red" band $\Delta\lambda_R$ and a polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linearly polarizing reflective panel 8', the linear polarization rotating element 9A', the "red" pass-band linearly polarizing reflective element 10A' and the broad-band linearly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ or "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_G^{LP2} , λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the linear polarization rotating element 9A' and reflected off the "red" pass-band linearly polarizing reflective element 10A' and retransmitted through the linear polarization rotating element 9A' and broad-band linear polarizing reflective panel 8' back into the backlighting structure for systemic recycling.

When a "green" subpixel is driven into its "bright" state as shown in Fig. 3A2, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ and a polarization state LP2 (i.e. λ_G^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the linear polarization rotating element 9B', the "green" pass-band linearly polarizing reflective element 10B' and the broad-band linearly polarizing reflective panel 11' without absorption.

In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_R^{LP2} λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8' and the linear polarization rotating element 9B' and reflected off the "green" pass-band linearly polarizing reflective element 10B' and retransmitted through the linear polarization rotating element 9B' and broad-band linear polarizing reflective panel 8' back into the backlighting structure for systemic recycling .

When a "blue" subpixel is driven into its "bright" state as shown in Fig. 3A2, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the linear polarization rotating element 9C', the "blue" pass-band linearly polarizing reflective element 10C' and the broad-band linearly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "green" band $\Delta\lambda_G$ and a polarization state LP2 (i.e. λ_R^{LP2} λ_G^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8' and the linear polarization rotating element 10C' and reflected off the "blue" pass-band linearly polarizing reflective element 9C' and retransmitted through the linear polarization rotating element 9C' and broad-band linearly polarizing reflective panel 8' back into the backlighting structure for systemic recycling .

As shown in Figs. 4A1 and 4A2, unpolarized light is produced within the backlighting structure and is composed of spectral components

having both LHCP and RHCP polarization states. Only spectral components having the RHCP polarization state are transmitted through the broad-band circularly polarizing reflective panel 8'' adjacent the backlighting panel 7, whereas spectral components having polarization state RHCP incident thereon are reflected therefrom without energy loss or absorption. Spectral components reflecting off broad-band circularly polarizing reflective panel 8'' on the backlighting structure side strike quasi-diffusive reflector 7A, and undergo a polarization inversion (i.e. LHCP to RHCP or RHCP to LHCP). This reflection process occurs independent of wavelength. The spectral components having the RHCP polarization state are transmitted through the broad-band circularly polarizing reflective panel 8''.

When a circular polarization rotating element associated with a red, green or blue subpixel is driven into its inactive-state as shown in Fig. 4A1, the polarization rotating element associated therewith transmits the spectral components therethrough independent of wavelength while effecting an orthogonal conversion in polarization state (i.e. LHCP to RHCP and RHCP to LHCP), thereby producing a "dark" subpixel level in response to the inactive-state into which it has been driven.

When a "red" subpixel is driven into its "dark" state shown in Fig. 4A1, spectral components within the backlighting structure having wavelengths within the "red" , "green" or "blue" band $\Delta\lambda_R$ and polarization state RHCP (i.e. λ_R^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', the circular polarization rotating element 9A'' and the "red" pass-band circularly polarizing reflective element 10A'' and reflect off broad-band circularly polarizing reflective panel 11'' without absorption. These reflected "red", "green" and "blue" spectral components with the RHCP polarization state (i.e.

λ_R^{RHCP}, λ_G^{RHCP}, λ_B^{RHCP}) are retransmitted through pass-band circularly polarizing reflective element 10A'', circular polarization rotating element 9A'' , and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling .

When a "green" subpixel is driven into its "dark" state shown in Fig. 4A1, spectral components within the backlighting structure having wavelengths within the "red" , "green" or "blue" band and polarization state RHCP (i.e. λ_R^{RHCP}, λ_G^{RHCP}, λ_B^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', circular polarization rotating element 9B'' and the "green" pass-band circularly polarizing reflective element 10B'' and reflect off broad-band circularly polarizing reflective panel 11'' without absorption. These reflected "red", "green" and "blue" spectral components with the LHCP polarization state (i.e. λ_R^{RHCP}, λ_G^{RHCP}, λ_B^{RHCP}) are retransmitted through pass-band circularly polarizing reflective element 10B'', circular polarization rotating element 9B'' , and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling s.

When a "blue" subpixel is driven into a "dark" state shown in Fig. 4A1, spectral components within the backlighting structure having wavelengths within the "red" , "green" or "blue" band $\Delta\lambda_R$ and polarization state RHCP (i.e. λ_R^{RHCP}, λ_G^{RHCP}, λ_B^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', circular polarization rotating element 9C'', the "blue" pass-band circularly polarizing reflective element 10C'' and reflect off broad-band circularly polarizing reflective panel 11'' without absorption. These reflected "red", "green" and "blue" spectral components with the RHCP polarization state (i.e. λ_R^{RHCP}, λ_G^{RHCP}, λ_B^{RHCP}) are retransmitted through pass-

band circularly polarizing reflective element 10C'', circular polarization rotating element 9C'' , and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling .

When a circular polarization rotating element is controlled in its active-state as shown in Fig. 4A2, the element transmits the spectral components therethrough independent of wavelength without effecting a conversion in polarization state, thereby producing a "bright" subpixel level in response to the active-state into which it has been driven.

When a "red" subpixel is driven into its "bright" state as shown in Fig. 4A2, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and a polarization state RHCP (i.e. λ_R^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', circular polarization rotating element 9A'', the "red" pass-band circularly polarizing reflective element 10A'' and the broad-band circularly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ or "blue" band $\Delta\lambda_B$ and a polarization state RHCP (i.e. λ_G^{RHCP} λ_B^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'' and the circular polarization rotating element 9A'' and reflected off the "red" pass-band circularly polarizing reflective element 10A'' and retransmitted through the circular polarization rotating element 9A'' and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling.

When a "green" subpixel is driven into its "bright" state as shown in Fig. 4A2, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ and a polarization state RHCP

(i.e. λ_G^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', the circular polarization rotating element 9B'', the green" pass-band circularly polarizing reflective element 10B'' and the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "blue" band $\Delta\lambda_B$ and a polarization state RHCP (i.e. λ_R^{RHCP} λ_B^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'' and the circular polarization rotating element 9B'' and reflected off the "green" pass-band circularly polarizing reflective element 10B'' and retransmitted through the circular polarization rotating element 9B'' and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling .

When a "blue" subpixel is driven into its "bright" state as shown in Fig. 4A2, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and a polarization state RHCP (i.e. λ_B^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'', the circular polarizing rotating element 10C'', the "blue" pass-band circularly polarizing reflective element 9C'' and the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "green" band $\Delta\lambda_G$ and a polarization state RHCP (i.e. λ_R^{RHCP} λ_G^{RHCP}) are transmitted through the broad-band circular polarizing reflective panel 8'' and the circular polarization rotating element 9C'' and reflected off the "blue" pass-band circularly polarizing reflective element 10C'' and

retransmitted through the circular polarization rotating element 9C'' and broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for systemic recycling .

Overview on the LCD Panel Construction of Fig. 8

In the second generalized LCD panel construction shown in Fig. 8, spectral filtering occurs before spatial intensity modulation. In the second illustrative embodiment of this LCD panel construction shown in Figs. 9A1 and 9A2, linear polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In the second illustrative embodiment of this LCD panel construction shown in Figs. 10A1 and 10A2, circular polarization techniques are used to carry out the spatial intensity modulation and spectral filtering functions employed therein. In each such illustrative embodiment, modifications are made among the various components of the LCD panel shown in Fig. 8. Details regarding such modifications will be described hereinafter.

In Fig. 8, the subcomponent structure of the second generalized embodiment of the LCD panel hereof is shown in great clarity. As shown, the second generalized embodiment of the LCD panel 2 comprises: a backlighting structure 7 including a quasi-diffusive reflector 7A, for producing a plane of broad-band light having a substantially uniform light intensity over the x and y coordinate axes thereof; a broad-band polarizing reflective panel 8; a pixelated array 10 of pass-band polarizing reflective (filter) elements 10A, 10B, 10C , for spectral filtering of light produced from the backlighting structure; a pixelated array 9 of polarization direction rotating elements 9A, 9B, 9C for spatial intensity modulation of light produced from the pixelated

array of pass-band polarizing reflective (filter) elements; and a broad-band polarizing reflective panel 11 for cooperative operation with the pixelated array of polarization direction rotating elements 9 and the pixelated array of pass-band polarizing reflective (filter) elements 10. In an alternative embodiment, a broad-band absorptive-type panel can be substituted for broad-band polarizing reflective panel 11 in order to reduce glare due to ambient light incident upon the LCD panel during operation.

In order to produce high-resolution color images, the spatial period of the pixelated arrays 9 and 10 is selected to be relatively small in relation to the overall length and height dimensions of the LCD panel. In a conventional manner, each pixel structure in the LCD panel is comprised of a red subpixel 13A, a green subpixel 13B and blue subpixel 13C, as illustrated in Fig. 2A. As shown therein, each red subpixel structure 13A comprises a red-band spectral filtering element 10A which is spatially registered with a first polarization direction rotating element 9A. Each green subpixel structure 13B comprises a green-band spectral filtering element 10B spatially registered with a second polarization direction rotating element 9B. Each blue subpixel element 13C comprises a blue-band spectral filtering element 10C spatially registered with a third polarization direction rotating element 9C. The output intensity (i.e. brightness or darkness level) of each red subpixel structure is controlled by applying pulse-width modulated voltage signal V_R to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each green subpixel structure is controlled by applying pulse-width modulated voltage signal V_G to the electrodes of its electrically-controlled spatially intensity modulating element. The output intensity of each blue

subpixel structure is controlled by providing pulse-width modulated voltage signal V_B applied to the electrodes of its electrically-controlled spatially intensity modulating element. By simply controlling the width of the above-described voltages V_R, V_G, V_B, the grey-scale intensity (i.e. brightness) level of each subpixel structure can be controlled in a manner well known in the LCD panel art.

First Illustrative Embodiment Of the LCD Panel Construction of Fig. 8

In the illustrative embodiments shown in Figs. 9A1 and 9A2, the backlighting structure 7 is realized in a manner described above. Understandably, there are other techniques for producing a plane of unpolarized light for use in connection with the LCD panel of the present invention.

In the illustrative embodiment of Fig. 9A1 and 9A2, the pixelated array of polarization rotating elements 9 is realized as an array of linear polarization rotating elements 9' formed within a single plane. As indicated in Figs. 9A1 and 9A2, each pass-band linear polarizing reflective element 9A', 9B', 9C' in the pixelated pass-band linear polarizing panel 9' has a LP2 characteristic polarization state, whereas the broad-band linear polarizing reflective panel 8' adjacent the backlighting structure has an LP1 characteristic polarization state and the broad-band linear polarizing reflective panel 11' has an LP2 characteristic polarization state.

A preferred method of making the broad-band linearly polarizing reflective panels 8' and 11' is disclosed in great detail in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material" published on May 9, 1997 under International Publication Number WO 97/16762, which is incorporated

herein by reference in its entirety. An alternative method of making broad-band linearly polarizing reflective panels 8' and 11' is disclosed in EPO Application No. 94200026.6 entitled "Cholesteric Polarizer and Manufacture Thereof", incorporated herein by reference. The reflection characteristics of the broad-band linearly polarizing reflective panel 8' are graphically illustrated in Fig. 9B for incident light having linear polarization state LP1, whereas the reflection characteristics of the broad-band linearly polarizing reflective panel 11' are graphically illustrated in Fig. 9C for incident light having linear polarization state LP2.

In the illustrative embodiment of Figs. 9A1 and 9A2, the polarization rotating array 9 is realized as an array of electronically-controlled linear polarization rotating elements 9A', 9B', 9C' for rotating the linearly polarized electric field along LP1 to the LP2 polarization direction as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 9A1 and 9A2, each electronically-controlled linear polarization rotating element can be realized as a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by a control voltage well known in the art. To construct the linear polarization rotating elements, thin film transistors (TFTs) can be used to create the necessary voltages across a layer of liquid crystal material to achieve alignment of the liquid crystal molecules and thus cause the corresponding element to not rotate the polarization direction of transmitted light passing therethrough. In its electrically-inactive state (i.e. no voltage is applied), the electric field intensity of light exiting from the cell is substantially zero and thus a "dark" subpixel level is produced. In its electrically-active state (i.e. the

threshold voltage V_T is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 9A1 and 9A2, the pixelated array of spectral filtering elements 10 is realized as an array of pass-band linear polarizing reflective elements 10A', 10B', 10C' formed within a single plane. Broad-band linearly polarizing reflective panel 11' is laminated to the pixelated array of spectral filtering elements 10.

As shown in Fig. 9D, each pass-band polarizing reflective element 10C' associated with a "blue" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the red reflective band $\Delta\lambda_R$, whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the blue reflective band $\Delta\lambda_B$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "blue" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 9E, each pass-band polarizing reflective element 10B' associated with a "green" subpixel in the pixelated pass-band linear polarizing panel 10" is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the red reflective band $\Delta\lambda_R$ or the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band

$\Delta\lambda_G$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "green" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 9F, each pass-band polarizing reflective element 10C' associated with a "red" subpixel in the pixelated pass-band linear polarizing panel 10' is particularly designed to reflect nearly 100% all spectral components having the LP2 characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ or the blue reflective band, whereas all spectral components having the LP2 characteristic polarization state and a wavelength within the red reflective band $\Delta\lambda_R$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "red" subpixel is "tuned" during fabrication in the manner described hereinabove.

The pixelated pass-band linear polarizing reflective panel 9' can be fabricated in a manner similar to the way described in the LCD panel fabrication method described hereinabove.

Notably, the above description of the first illustrative embodiment of LCD panel construction of Fig. 8 has assumed that the complete surface area associated with each subpixel region is available for light intensity modulation and spectral filtering functions. In practice, each subpixel region of the LCD panel includes (i) a light transmission region (i.e. aperture region) 50 in which pass-band linear polarizing reflective element is located, and a light blocking region (i.e. stop portion) 51 in which TFTs, wires, etc. are located.

In order to maximize the light transmission efficiency of the LCD

panel, broad-band reflective film material (e.g. broad-band reflector film) 53 is applied over the light blocking region 51 of each subpixel region on the backside thereof. In the first illustrative embodiment described above, a pattern of broad-band reflector film, corresponding to the light blocking portions of the subpixel regions, can be applied to the back surface of the broad-band polarizing reflective panel 8' (facing the backlighting structure) or pixelated spectral filtering panel 10', in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask which prevents the absorption and scattering of produced light from structures associated with the light blocking portion of the subpixels of the LCD panel.

In order to reduce glare at the surface of the LCD panel due to ambient light incident thereon, a broad-band absorptive film material (e.g. carbonized polymer film) 54 is applied over the light blocking region 51 of each subpixel region on the front surface thereof. In the first illustrative embodiment described above, a pattern of broad-band absorption film, corresponding to the light blocking portions of the subpixel regions, can be applied to the front surface of the broad-band polarizing panel 11', in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask which prevents reflection and scattering of ambient light off structures associated with the light blocking portion of the subpixels of the LCD panel, and thus reduces glare at the surface of the LCD panel due to ambient light incident thereon.

Second Illustrative Embodiment Of the LCD Panel Construction of Fig. 8

In the illustrative embodiments shown in Figs. 10A1 and 10A2, the backlighting structure 7 is realized in a manner described above.

Understandably, there are other techniques for producing a plane of unpolarized light for use in connection with the LCD panel of the present invention.

In the illustrative embodiment of Figs. 10A and 10A2, the pixelated polarization rotating array 9 shown in Fig. 8 is realized as an array of electronically-controlled circular polarization rotating elements 9'' which rotate the circularly polarized electric field from the LHCP direction to the RHCP direction as the light rays are transmitted through the spatially corresponding pixels in the LCD panel. In the illustrative embodiment of Figs. 10A1 and 10A2, each electronically-controlled circular polarization rotating element 9A'', 9B'', 9C'' can be realized as a π-cell, whose operation is by controlled by a control voltage well known in the art. In its electrically-inactive state (i.e. no-voltage is applied), the electric field intensity of light exiting from each π cell is substantially zero and thus a "dark" level is produced. In its electrically-active state (i.e. threshold voltage V_T is applied), the electric field intensity of light exiting from the cell is substantially non-zero and thus a "bright" subpixel level is produced.

In the illustrative embodiment of Fig. 10A1 and 10A2, the array of spectral filtering elements 10A'', 10B'', 10C'' is realized as an array of pass-band circularly polarizing reflective elements 10'' formed within a single plane. As indicated in Figs. 10A1 and 10A2, each pass-band circularly polarizing reflective element in the pixelated pass-band circularly polarizing panel 10'' has a RHCP characteristic polarization state, whereas the broad-band circularly polarizing reflective panel 8'' adjacent backlighting panel 7 has an LHCP characteristic polarization state and the broad-band circularly polarizing reflective panel 11'' has a characteristic polarization state RHCP.

As shown in Fig. 10D, each pass-band polarizing reflective element 10C'' associated with a "blue" subpixel in the pixelated pass-band circularly polarizing panel 10 is particularly designed to reflect nearly 100% all spectral components having the RHCP characteristic polarization state and wavelengths within the green reflective band $\Delta\lambda_G$ [redacted] blue reflective band $\Delta\lambda_B$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "blue" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 10E, each pass-band polarizing reflective element 10B'' associated with a "green" subpixel in the pixelated pass-band circular polarizing panel 10 is particularly designed to reflect nearly 100% all spectral components having the RHCP characteristic polarization state and wavelengths within the red reflective band $\Delta\lambda_R$ and the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the RHCP characteristic polarization state and a wavelength within the green reflective band $\Delta\lambda_G$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "green" subpixel is "tuned" during fabrication in the manner described hereinabove.

As shown in Fig. 10F, each pass-band polarizing reflective element 10A'' associated with a "red" subpixel in the pixelated pass-band circular polarizing panel 10 is particularly designed to reflect nearly 100% all spectral components having the RHCP characteristic

polarization state and wavelengths within the green reflective band $\Delta\lambda_G$ and the blue reflective band $\Delta\lambda_B$, whereas all spectral components having the RHCP characteristic polarization state and a wavelength within the red reflective band $\Delta\lambda_R$ are transmitted nearly 100% through the pass-band polarizing reflective element. The pass-band polarizing reflective element associated with each "red" subpixel is "tuned" during fabrication in the manner described hereinabove.

The preferred method of making broad-band circular polarizing reflective panels 8'' and 11'' shown in Figs. 10A1 and 10A2 is disclosed in International Application Number PCT/US96/17464 entitled "Super Broad-band Polarizing Reflective Material", supra. The pixelated pass-band circularly polarizing reflective panel 10'' can be fabricated in a manner similar to the way described in LCD panel fabrication method described in detail hereinabove.

Notably, the above description of the second illustrative embodiment of LCD panel construction of Fig. 8 has assumed that the complete surface area associated with each subpixel region is available for light intensity modulation and spectral filtering functions. In practice, each subpixel region of the LCD panel includes (i) a light transmission region (i.e. aperture region) 50 in which pass-band linear polarizing reflective element is located, and a light blocking region (i.e. stop portion) 51 in which TFTs, wires, etc. are located.

In order to maximize the light transmission efficiency of the LCD panel, broad-band reflective film material (e.g. broad-band reflector film) 53 is applied over the light blocking region 51 of each subpixel region on the backside thereof. In the first illustrative embodiment described above, a pattern of broad-band reflector film, corresponding

to the light blocking portions of the subpixel regions, can be applied to the back surface of the broad-band polarizing reflective panel 8'' (facing the backlighting structure) or pixelated spectral filtering panel 10'', in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask which prevents the absorption and scattering of produced light from structures associated with the light blocking portion of the subpixels of the LCD panel.

In order to reduce glare at the surface of the LCD panel due to ambient light incident thereon, a broad-band absorptive film material (e.g. carbonized polymer film) 54 is applied over the light blocking region 51 of each subpixel region on the front surface thereof. In the first illustrative embodiment described above, a pattern of broad-band absorption film, corresponding to the light blocking portions of the subpixel regions, can be applied to the front surface of the broad-band polarizing panel 11'', in spatial registration with the light blocking portions of the subpixel regions. This provides a light reflective mask which prevents reflection and scattering of ambient light off structures associated with the light blocking portion of the subpixels of the LCD panel, and thus reduces glare at the surface of the LCD panel due to ambient light incident thereon.

<u>Operation Of The First And Second Illustrative Embodiments of the LCD Panel of the Second Generalized Embodiment of the Present Invention</u>

Having described in detail how to make the LCD panels illustrated in Figs. 8, 9A1, 9A2, and 10A1 and 10A2, it is appropriate at this juncture to now describe their operation with reference to the exemplary pixel structure detailed in such figure drawings.

As shown in Figs. 9A1 and 9A2, unpolarized light is produced within

the backlighting structure and is composed of spectral components having both LP1 and LP2 polarization states. Only spectral components having the LP2 polarization state are transmitted through the broad-band linear polarizing reflective panel 8' adjacent the backlighting panel 7, whereas spectral components having polarization state LP1 incident thereon are reflected therefrom without energy loss or absorption. Spectral components reflecting off broad-band linear polarizing reflective panel 8' on the backlighting structure side strike quasi-diffusive reflector 7A, and undergo a polarization inversion (i.e. LP1 to LP2 and LP2 to LP1). This reflection process occurs independent of wavelength. The spectral components having the LP2 polarization state are retransmitted through the broad-band linear polarizing reflective panel 8' adjacent the backlighting structure.

When a linear polarization rotating element 9A', 9B', 9C' is controlled in its inactive-state as shown in Fig. 9A1, the linear polarization rotating element will transmit the spectral components therethrough independent of wavelength while effecting a conversion in polarization state (i.e. LP1 to LP2 and LP2 to LP1), thereby producing a "bright" subpixel level in response to the inactive-state into which it has been driven.

When a "red" subpixel is driven into its "bright" state as shown in Fig. 9A1, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and a polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "red" pass-band linearly polarizing reflective element 10A', the linear polarization direction rotating element 9A' and the broad-band linearly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having

wavelengths within the "green" band $\Delta\lambda_G$ and "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_G^{LP2} λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8' and are reflected off the "red" pass-band linearly polarizing reflective element 10A' and retransmitted through broad-band linear polarizing reflective panel 8' back into the backlighting structure for systemic recycling s.

[redacted] Fig. 9A1, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ and a polarization state LP2 (i.e. λ_G^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "green" pass-band linearly polarizing reflective element 10B', the linear polarization direction rotating element 9B' and the broad-band linearly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_R^{LP2} λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8' and reflected off the "green" pass-band linearly polarizing reflective element 10B' and retransmitted through broad-band linear polarizing reflective panel 8' back into the backlighting structure for systemic recycling.

When a "blue" subpixel is driven into its "bright" state as shown in Fig. 10A1, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and a polarization state LP2 (i.e. λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "blue" pass-band linearly polarizing reflective element 10C', the linear polarization direction rotating element 9C' and

the broad-band linearly polarizing reflective panel 11' without absorption. In this state, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and "green" band $\Delta\lambda_G$ and a polarization state LP2 (i.e. λ_R^{LP2} λ_G^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8' and reflected off the "blue" pass-band linearly polarizing reflective element 10C' and retransmitted through the broad-band linearly polarizing reflective panel 8' back into the backlighting structure for systemic recycling .

When a linear polarization rotating element associated with a red, green or blue subpixel is driven into its active-state as shown in Fig. 9A2, the linear polarization rotating element associated therewith will transmit the spectral components therethrough independent of wavelength without effecting an orthogonal conversion in polarization state (i.e. LP1 to LP1 or LP2 to LP2), thereby producing a "dark" subpixel level in response to the active-state into which it has been driven.

When a "red" subpixel is driven into its "dark" state shown in Fig. 9A2, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and polarization state LP2 (i.e. λ_R^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "red" pass-band linearly polarizing reflective element 10A' and linear polarization direction rotating element 9A' and reflect off broad-band linearly polarizing reflective panel 11' without absorption. The reflected "red" spectral components with the LP2 polarization state (i.e. λ_R^{LP2}) are then retransmitted through the linear polarization direction rotating element 9A', the pass-band linearly polarizing reflective

element 10A', and the broad-band linearly polarizing reflective panel 8" back into the backlighting structure for recycling among neighboring subpixels. At the same time, spectral components having wavelengths within the "green" band $\Delta\lambda_G$ or "blue" band $\Delta\lambda_B$ and polarization state LP2 (i.e. λ_G^{LP2}, λ_B^{LP2}) are transmitted through broad-band linearly polarizing reflective panel 8' and reflected off the "red" pass-band polarizing reflective element 10A' and then retransmitted through the broad-band linearly polarizing reflective panel 8' back into the backlighting structure for recycling among neighboring subpixels.

When a "green" subpixel is driven into its "dark" state shown in Fig. 9A2, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ and polarization state LP2 (i.e. λ_G^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "green" pass-band linearly polarizing reflective element 10B' and linear polarization direction rotating element 9B' and reflect off broad-band linearly polarizing reflective panel 11' without absorption. The reflected "green" spectral components with the LP2 polarization state (i.e. λ_G^{LP2}) are then retransmitted through the linear polarization direction rotating element 9B' (without polarization rotation), the pass-band linearly polarizing reflective element 10B', and the broad-band linearly polarizing reflective panel 8' back into the backlighting structure for recycling among neighboring subpixels. At the same time, spectral components having wavelengths within the "red" band $\Delta\lambda_R$ or "blue" band $\Delta\lambda_B$ and polarization state LP2 (i.e. λ_R^{LP2}, λ_B^{LP2}) are transmitted through broad-band polarizing reflective panel 8' and reflected off the "green" pass-band polarizing reflective element

10B' , and then retransmitted through the broad-band linearly polarizing reflective panel 8' back into the backlighting structure for recycling among neighboring subpixels.

When a "blue" subpixel is driven into its "dark" state shown in Fig. 9A2, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and polarization state LP2 (i.e. λ_B^{LP2}) are transmitted through the broad-band linear polarizing reflective panel 8', the "blue" pass-band linearly polarizing reflective element 10C' and linear polarization direction rotating element 9C' and reflect off the broad-band linearly polarizing reflective panel 11' without absorption. The reflected "blue" spectral components with the LP2 polarization state (i.e. λ_B^{LP2}) are then retransmitted through the linear polarization direction rotating element 9C' (without polarization rotation), the pass-band linearly polarizing reflective element 10C', and the broad-band linearly polarizing reflective panel 8' back into the backlighting structure for recycling among neighboring subpixels. At the same time, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "green" band $\Delta\lambda_G$ and polarization state LP2 (i.e. λ_R^{LP2} , λ_G^{LP2}) are transmitted through broad-band polarizing reflective panel 8' and reflected off the "blue" pass-band polarizing reflective element 10B' and then retransmitted through the broad-band linearly polarizing reflective panel 8 back into the backlighting structure for recycling among neighboring subpixels.

As shown in Figs. 10A1 and 10A2, unpolarized light is produced within the backlighting structure and is composed of spectral components having both LHCP and RHCP polarization states. Only spectral components within the backlighting structure having the RHCP

polarization state are transmitted through the broad-band circularly polarizing reflective panel 8'' adjacent the backlighting structure 7, whereas spectral components therewithin having polarization state LHCP incident thereon are reflected therefrom without energy loss or absorption. Spectral components reflecting off broad-band circularly polarizing reflective panel 8'' on the backlighting structure side strike quasi-diffusive reflector 7A and undergo a polarization inversion (i.e. LHCP to RHCP and RHCP to LHCP). This reflection process occurs independent of wavelength. Only spectral components having the RHCP polarization state are retransmitted through the broad-band circularly polarizing reflective panel along the projection axis of the LCD panel.

When a circular polarization rotating element associated with a red, green or blue subpixel is driven into its active-state as shown in Fig. 10A1, the circular polarization rotating element associated therewith transmits the spectral components therethrough independent of wavelength while effecting an orthogonal conversion in polarization state (i.e. LHCP to RHCP and RHCP to LHCP), thereby producing a "bright" subpixel level in response to the active-state into which it has been driven.

When a "red" subpixel is driven into its "bright" state shown in Fig. 10A1, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and polarization state RHCP (i.e. λ_R^{RHCP}) are transmitted through the broad-band linear polarizing reflective panel 8'', the "red" pass-band circularly polarizing reflective element 10A'', the circular polarization direction rotating element 9A'', and the broad-band circularly polarizing reflective panel 11'' without absorption. The "green" and "blue" spectral components with the RHCP polarization state (i.e. λ_G^{RHCP}, λ_B^{RHCP}) are transmitted through the broad-

band linear polarizing reflective panel 8' and reflected off the "red" pass-band circularly polarizing reflective element 10A'', and are retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a "green" subpixel is driven into its "bright" state shown in Fig. 10A1, spectral components having wavelengths within the "green" band and polarization state RHCP (i.e. λ_G^{RHCP}) are transmitted through the broad-band linear polarizing reflective panel 8', the "green" pass-band circularly polarizing reflective element 10B'', the circular polarization direction rotating element 9B'', and the broad-band circularly polarizing reflective panel 11'' without absorption. The "red" and "blue" spectral components with the RHCP polarization state (i.e. λ_R^{RHCP}, λ_B^{RHCP}) are transmitted through the broad-band linear polarizing reflective panel 8' and reflected off the "green" pass-band circularly polarizing reflective element 10B'', and are retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a "blue" subpixel is driven into its "bright" state shown in Fig. 10A1, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and polarization state RHCP (i.e. λ_B^{RHCP}) are transmitted through the broad-band linear polarizing reflective panel 8', the "blue" pass-band circularly polarizing reflective element 10C'', the circular polarization direction rotating element 9C'', and the broad-band circularly polarizing reflective panel 11'' without absorption. The "red" and "green" spectral components with the RHCP polarization state (i.e. λ_R^{RHCP}, λ_G^{RHCP}) are transmitted through the broad-

band linear polarizing reflective panel 8' and reflected off the "blue" pass-band circularly polarizing reflective element 10C'', and are retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a circular polarization rotating element is controlled in its inactive-state as shown in Fig. 10A2, the polarization rotating element transmits the spectral components therethrough independent of wavelength without effecting a conversion in polarization state, thereby producing a "dark" subpixel level.

When a "red" subpixel is driven into its "dark" state as shown in Fig. 10A2, spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ and a polarization state RHCP (i.e. λ_R^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'', the "red" pass-band circularly polarizing reflective element 10A'' and the circular polarization rotating element 9A'' and reflected off the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9A'', the "red" pass-band circular polarizing reflective element 10A'' and the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among the neighboring subpixels.

Spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ or "blue" band $\Delta\lambda_B$ and a polarization state RHCP (i.e. λ_G^{RHCP} λ_B^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'' and are reflected off

the "red" pass-band circularly polarizing reflective element 10A'' and retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a "green" subpixel is driven into its "dark" state as shown in Fig. 10A2, spectral components within the backlighting structure having wavelengths within the "green" band $\Delta\lambda_G$ and a polarization state RHCP (i.e. λ_G^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'', the "green" pass-band circularly polarizing reflective element 10B'', and the circular polarization rotating element 9B'' and reflected off the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9B'', the "green" pass-band circular polarizing reflective element 10B'' and the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among the neighboring subpixels. Spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "blue" band $\Delta\lambda_B$ and a polarization state RHCP (i.e. λ_R^{RHCP}, λ_B^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'' and are reflected off the "green" pass-band circularly polarizing reflective element 10B'' and retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

When a "blue" subpixel is driven into its "dark" state as shown in Fig. 10A2, spectral components within the backlighting structure having wavelengths within the "blue" band $\Delta\lambda_B$ and a polarization state RHCP

(i.e. λ_B^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'', the "blue" pass-band circularly polarizing reflective element 10C'', and the circular polarization rotating element 9C'' and reflected off the broad-band circularly polarizing reflective panel 11'' without absorption. In this state, these reflected spectral components are then retransmitted through the circular polarization rotating element 9C'', the "blue" pass-band circularly polarizing reflective element 10C'' and the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among the neighboring subpixels. Spectral components within the backlighting structure having wavelengths within the "red" band $\Delta\lambda_R$ or "green" band $\Delta\lambda_G$ and a polarization state RHCP (i.e. λ_R^{RHCP}, λ_G^{RHCP}) are transmitted through the broad-band circularly polarizing reflective panel 8'' and are reflected off the "blue" pass-band circularly polarizing reflective element 10C'' and retransmitted through the broad-band circularly polarizing reflective panel 8'' back into the backlighting structure for recycling among neighboring subpixels.

<u>Alternative Embodiments Of the LCD Panel Hereof</u>

Expectedly, the extinction ratio for the broad-band linear polarizing reflective panels employed in the LCD panels of Figs. 2 and 8 may be less than optimum. Consequently, a small percentage of incident light energy passing through the LCD panel will be imparted with the orthogonal polarization state and will be perceived by the viewer as spatial noise, degrading the image contrast attainable by the display system.

Surprisingly, it has been discovered that it is possible to markedly improve the contrast of image displayed from the LCD panels hereof by

employing energy absorbing polarizers within the LCD panel construction in a way which absorbs orthogonal "noise" components produced by the broad-band polarizing "reflective" panels employed therein, without effecting the light recycling mechanisms carried out at the various stages of the LCD panel. As will be described in greater detail below, this technique involves mounting to each broad-band polarizing reflective panel, an absorptive-type broad-band polarizing filter having a polarization state that is "matched" to the polarization state of its corresponding broad-band polarizing reflective panel. Modified versions of the four illustrative LCD panel embodiments hereof are shown in Figs. 11 through 14.

In Fig. 11, the LCD panel of Figs. 3A1 and 3A2 is shown modified by mounting a first broad-band absorptive linear polarizer 8A' to the front surface of broad-band polarizing reflective panel 8', and mounting a second broad-band absorptive linear polarizer 11A' to the front surface of broad-band polarizing reflective panel 11' . The polarization state of broad-band absorptive linear polarizer 8' is LP1 in order to match the LP1 polarization state of broad-band polarizing reflective panel 8' . Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8' , but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer 8A' through energy dissipation. Similarly, the polarization state of broad-band absorptive linear polarizer 11A' is LP1 in order to match the LP1 polarization state of broad-band polarizing reflective panel 11' . Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11' , but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction

ratio, is absorbed by the broad-band absorptive linear polarizer 11A' through energy dissipation. The use of broad-band absorptive linear polarizers 8A' and 11A' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel which, as shown in Fig. 2, extends from the backlighting structure towards the eyes of the viewer. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art. Preferably, these absorptive polarizing filter panels 8A' and 11A' are laminated directly onto broad-band polarizing reflective panels 8' and 11', respectively, during the fabrication process of the LCD panel.

In Fig. 12, the LCD panel of Figs. 4A1 and 4A2 is shown modified by mounting a first broad-band absorptive circular polarizer 8A'' to the front surface of broad-band circularly polarizing reflective panel 8'', and mounting a second broad-band absorptive circular polarizer 11A'' to the front surface of broad-band circularly polarizing reflective panel 11''. The polarization state of broad-band absorptive circular polarizer 8A'' is LHCP in order to match the LHCP polarization state of broad-band circularly polarizing reflective panel 8''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8'', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer 8A'' through energy dissipation. Similarly, the polarization state of broad-band absorptive circular polarizer 11A'' is RHCP in order to match the RHCP polarization state of broad-band polarizing reflective panel 11''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11'', but is transmitted (i.e.

leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer 11A'' through energy dissipation. The use of broad-band absorptive circular polarizers 8A'' and 11A'' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art. Preferably, these absorptive circularly polarizing filter panels 8A'' and 11A'' are laminated directly onto broad-band circularly polarizing reflective panels 8'' and 11'', respectively, during the fabrication process of the LCD panel.

In Fig. 13, the LCD panel of Figs. 9A1 and 9A2 is shown modified by mounting a first broad-band absorptive linear polarizer 8A' to the front surface of broad-band polarizing reflective panel 8', and mounting a second broad-band absorptive linear polarizer 11A' to the front surface of broad-band polarizing reflective panel 11' . The polarization state of broad-band absorptive linear polarizer 8A' is LP1 in order to match the LP1 polarization state of broad-band polarizing reflective panel 8' . Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8' , but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive linear polarizer 8A' through energy dissipation. Similarly, the polarization state of broad-band absorptive linear polarizer 11A' is LP2 in order to match the LP2 polarization state of broad-band polarizing reflective panel 11'. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11' , but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction

ratio, is absorbed by the broad-band absorptive linear polarizer 11A' through energy dissipation. Preferably, these absorptive polarizing filter panels 8A' and 11A' are laminated directly onto broad-band polarizing reflective panels 8 and 11, respectively. The use of broad-band absorptive linear polarizers 8A' and 8A'' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art.

In Fig. 14, the LCD panel of Figs. 10A1 and 10A2 is shown modified by mounting a first broad-band absorptive circular polarizer 8A'' to the front surface of broad-band circularly polarizing reflective panel 8'', and mounting a second broad-band absorptive circular polarizer 11A'' to the front surface of broad-band circularly polarizing reflective panel 11'' . The polarization state of broad-band absorptive circular polarizer 8A'' is LHCP in order to match the LHCP polarization state of broad-band circularly polarizing reflective panel 8''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 8'', but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer 8A'' through energy dissipation. Similarly, the polarization state of broad-band absorptive circular polarizer 11A'' is RHCP in order to match the RHCP polarization state of broad-band polarizing reflective panel 11''. Such polarization matching ensures that spectral energy which is not reflected from the broad-band polarizing reflective panel 11'' , but is transmitted (i.e. leaked) therethrough due to a suboptimal extinction ratio, is absorbed by the broad-band absorptive circular polarizer 11A'' through energy

dissipation. Preferably, these absorptive circularly polarizing filter panels 8A'' and 11A'' are laminated directly onto broad-band circularly polarizing reflective panels 8'' and 11'', respectively. The use of broad-band absorptive circular polarizers 8A'' and 11A'' substantially improves the contrast of images formed by the LCD panel, without reducing the light transmission efficiency along the light projection axis of the LCD panel. Such broad-band absorptive polarizers can be realized using dichroic polarizing material well known in the art.

In general, there are many applications to which the LCD panels of the present invention can be put. One such application is illustrated in Fig. 15. As shown, the LCD panel hereof can be integrated into a ultra-high brightness color image projection system of transportable design. In this particular embodiment, the image projection system is embodied within a laptop computer system having both direct and projection viewing modes, similar to the systems described in Applicant's: International Application No. PCT/US96/19718; International Application No. PCT/US95/12846; and International Application No. PCT/US95/05133, each incorporated herein by reference in its entirety.

<u>An Illustrative Application of LCD Panel Of The Present Invention</u>

As shown in Fig. 15, portable image projection system 30 comprises a number of subsystem components, namely: a compact housing of transportable construction having a display portion 31A with a frontwardly located display window 32, and a base portion 32B hingedly connected to the display portion 31A and having a keypad 33 and a pointing device 34; an LCD panel 2, 2' according to the present invention described above, mounted within the housing display portion 31A; an ultra-thin projection lens panel 35 (e.g. Fresnel lens,

holographic lens, etc.) laminated to the front surface of the LCD panel 2; a backlighting structure 7' of cascaded construction, mounted to the rear of the LCD panel 2 in a conventional manner; associated apparatus 36, (e.g. pixel driver circuitry, image display buffers, an image display controller, a rechargeable battery power supply, input/output circuitry for receiving video input signals from various types of external sources, microprocessor and associated memory, etc.), contained within the base portion 31B; a projection lens 37 supported by a bracket 38 which can be removed during the direct viewing mode and stored within a compartment 39 formed within the base portion of the housing; and an electro-optically controllable light diffusing panel 40 which does not scatter backprojected light in the projection viewing mode, and scatters back project light in the direct viewing mode.

In the direct-viewing mode of the system of Fig. 15, the projection lens 38 is stored within compartment 39, electro-optically controllable light diffusing panel 40 is switched to its light scattering state, and the backlighting structure produces light which is spatial-intensity modulated and spectrally filtered to produce color images on the surface of the LCD panel 2. In the projection-viewing mode, the projection lens 38 is mounted along the projection axis (optical axis) 41 of the Fresnel lens panel 35, electro-optically controllable light diffusing panel 40 is switched to its light non-scattering state, and the backlighting structure produces light which is spatial-intensity modulated and spectrally filtered to produce color images on the surface of the LCD panel 2. Projection lens 37 projects the formed color image onto a remote viewing surface 42 for projection viewing. By virtue of the ultra-high light transmission efficiency of the LCD panel 2 hereof, the system of Fig. 15 can projected bright color images onto remote surfaces without

the use of external high-intensity lighting sources required by prior art LCD projection systems. In portable applications, such images can be projected using the battery power source aboard the transportable system. With this design, there is not need for a rearwardly opening window in the back of display housing portion 31A, required of prior art projection system. When not in use, the system easily folds into a ultra-slim book-like configuration for easy of storage and transportability.

Modifications

Having described in the illustrative embodiments of the present invention, several modifications readily come to mind.

In each illustrative embodiment of the LCD panel hereof, the light "reflecting" properties of the subpixel spectral filter elements 10A, 10B, 10C have been realized using the polarization-reflective properties of CLC materials. It is understood, however, that these subcomponents of the LCD panel of the present invention may be realized using other enabling technologies, such as: (i) holographic reflective filter technology of the type disclosed in "Holographic Color Filters for LCDs" by John Biles, published in SID 94 DIGEST, pages 403-406; and/or (ii) thin-film optical interference filter technology of the type disclosed in "Design Issues in Using Thin-Film Optical Interference Filters as Color Filters for LCD System Applications" by S-F. Chen and H-P D. Shieh, published in SID 94 DIGEST (1994), pages 411-416; each being incorporated herein by reference. In such alternative embodiments, it would be preferred to employ broad-band polarizing reflective panels 8 and 11 having the polarization reflective properties as described hereinabove so that the systemic light recycling process of the present invention is preserved.

The modifications described above are merely exemplary. It is understood that other modifications to the illustrative embodiments will readily occur to persons with ordinary skill in the art. All such modifications and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying Claims to Invention.

CLAIMS TO INVENTION

1. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined image display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over which spectral components of light are intensity modulated to produce an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis, said distribution of light consisting of spectral components of produced light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum;

spatial intensity modulation means for spatial-intensity modulating said distribution of light at each said subpixel region in accordance with a plurality of subpixel drive signals, said spatial intensity modulation means providing at each said subpixel region an intensity modulating element for modulating the intensity of said produced light transmitted through said subpixel region so as to produce an intensity level at said subpixel region;

spectral filtering means for spectral filtering said distribution of light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing at each said subpixel region a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within

said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region; and

systemic light recycling means involving said light producing means, said spatial intensity modulation means, and said spectral filtering means, for recycling spectral components of light at each said subpixel region within each said pixel region of said predefined image display area.

2. The LCD panel construction of claim 1, wherein, within each said pixel region, the spectral components of said produced light not transmitted through one said subpixel region within said pixel region are reflected at either said light producing means, said spatial intensity modulation means or said spectral filtering means, within the spatial extent of said subpixel region for retransmission through the other said subpixel regions within said pixel region, thereby substantially increasing the brightness of said images produced from said predefined image display area.

3. The LCD panel construction of claim 1, wherein said plurality of subpixel regions within each said pixel region comprise a "red" subpixel region having a "red" pass-band, a "green" subpixel region having a "green" pass-band, and a "blue" subpixel region having a "blue" pass-band.

4. The LCD panel construction of claim 3, wherein said "red" pass-band transmits spectral components of light within said "red" pass-band and reflects substantially all spectral components of light within said "green"

pass-band and said "blue" pass-band, wherein said said "green" pass-band transmits spectral components of light within said "green" pass-band and reflects substantially all spectral components of light within said "red" pass-band and said "blue" pass-band, and wherein said said "blue" pass-band transmits spectral components of light within said "blue" pass-band and reflects substantially all spectral components of light within said "red" pass-band and said "green" pass-band.

5. The LCD panel of claim 1,

wherein each said spectral component of light produced from said said light producing means has a predetermined polarization state;

wherein each said intensity modulating element modulates the intensity of spectral components of light transmitted through said subpixel region in a manner dependent upon the polarization state of said spectral components; and

wherein each said spectral filtering element transmits only spectral components of said produced light having wavelengths within said predefined spectral band and reflects spectral components of produced light having wavelengths outside said predefined spectral band in a manner dependent upon the polarization state of said spectral components and said predetermined polarization state.

6. The LCD panel construction of claim 1, which further comprises

glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

7. The LCD panel construction of claim 6, wherein said glare reduction means comprises broad-band absorptive-type polarizating material.

8. The LCD panel construction of claim 7, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

9. The LCD panel construction of claim 8, wherein said broad-band absorptive-type polarizing material is operably associated with said spectral filtering means.

10. The LCD panel construction of claim 1, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

11. The LCD panel construction of claim 10, wherein said contrast enhancement means comprises broad-band absorptive-type polarizing material.

12. The LCD panel construction of claim 11, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

13. The LCD panel construction of claim 12, wherein said broad-band absorptive-type polarization structure is operably associated with said spectral filtering means.

14. The LCD panel construction of claim 1, wherein each said spectral filtering element is an optical element made from holographic-type material.

15. The LCD panel construction of claim 1, wherein each said spectral filtering element is an optical element made from interference-type material.

16. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over which spectral components of light are intensity modulated to produce an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis in the direction of a viewer, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum and each said spectral component of said produced light along said projection axis having a second linear polarization state orthogonal to a first linear polarization state;

spatial intensity modulation means, disposed adjacent said light producing means, for spatial-intensity modulating said distribution of light at each said subpixel region, said spatial intensity modulation means providing each said subpixel region with an intensity modulating element for modulating the intensity of spectral components of said produced light transmitted through said subpixel region so as to

produce an intensity level at said subpixel region controlled by a subpixel drive signal associated with said subpixel region; and

spectral filtering means, disposed adjacent said spatial intensity modulation means, for spectral filtering said distribution of produced light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing each said subpixel region with a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region controlled by said subpixel drive signal associated with said subpixel region.

17. The LCD panel construction of claim 16, wherein said light producing means is a backlighting structure comprising:

a light source for producing said spectral components of produced light over said visible band;

a quasi-specular reflector for reflecting spectral components of produced light and changing, upon reflection, the polarization state thereof from said first linear polarization state to said second linear polarization state and from said second linear polarization state to said first linear polarization state;

a first broad-band linearly polarizing reflective panel for transmitting spectral components of said produced light having said second linear polarization state and reflecting reflecting spectral components of said produced light having said first linear polarization state.

18. The LCD panel construction of claim 17, wherein said backlighting structure further comprises

a light guiding panel for guiding said produced light over said predefined display area.

19. The LCD panel construction of claim 16, wherein said spatial intensity modulation element at each said subpixel region comprises

an electronically-controlled linear polarization direction rotating element for rotating the polarization direction of said spectral components transmitted through said subpixel region in response to said subpixel driver signal associated with said subpixel.

20. The LCD panel construction of claim 19, wherein each electronically-controlled linear polarization rotating element comprises a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by said subpixel drive signal associated with said subpixel region.

21. The LCD panel construction of claim 17, wherein said spectral filtering means comprises:

a second broad-band linearly polarizing reflective panel for reflecting spectral components of said produced light having said first linear polarization state and transmitting spectral components of said produced light having said second linear polarization state; and

a pass-band linearly polarizing reflective element at each said subpixel region for transmitting spectral components of said produced light having said first linear polarization state and spectral components

of produced light having wavelengths within said predefined spectral band and said second linear polarization state, and reflecting spectral components of said produced light having wavelengths outside said predefined spectral band and said second linear polarization state.

22. The LCD panel construction of claim 16, wherein said subpixels within each said pixel region comprises:

a "red" subpixel region having a "red" reflective band;

a "green" subpixel region having a "green" reflective band; and

a "blue" subpixel region having a "blue" reflective band.

23. The LCD panel construction of claim 22, wherein said spectral filtering means comprises

a broad-band linearly polarizing reflective panel for reflecting spectral components of said produced light having said second linear polarization state and transmitting spectral components of said produced light having said first linear polarization state;

a first pass-band polarizing reflective element at each said "blue" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a wavelength within said "green" reflective band or said red reflective band, whereas all spectral components having said second linear polarization state or a wavelength within said blue reflective band are transmitted nearly 100% through said pass-band polarizing reflective element;

a second pass-band polarizing reflective element at each said "green" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a

wavelength within said red reflective band or said blue reflective band, whereas all spectral components having said second polarization state or a wavelength within said green reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "green" subpixel region; and

a third pass-band polarizing reflective element at each said "red" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a wavelength within said green reflective band or said blue reflective band, whereas all spectral components having said second linear polarization state or a wavelength within said red reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "red" subpixel region.

24. The LCD panel construction of claim 23, wherein said broad-band linearly polarizing reflective panel comprises a broad-band cholesteric liquid crystal (CLC) panel and a broad-band $\pi/2$-phase retardation structure.

25. The LCD panel construction of claim 23,

wherein said first pass-band polarizing reflective element comprises a first spectrally-tuned CLC element and a $\pi/2$-phase retardation structure;

wherein said second pass-band polarizing reflective element comprises a second spectrally-tuned CLC element and a $\pi/2$-phase retardation structure;

wherein said third pass-band polarizing reflective element comprises a third spectrally-tuned CLC element and a $\pi/2$-phase

retardation structure.

26. The LCD panel construction of claim 16, which further comprises glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

27. The LCD panel construction of claim 26, wherein said glare reduction means comprises a broad-band absorptive-type linear polarization structure.

28. The LCD panel construction of claim 27, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spatial intensity modulation means.

29. The LCD panel construction of claim 27, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spectral filtering means.

30. The LCD panel construction of claim 16, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

31. The LCD panel construction of claim 30, wherein said contrast enhancement means comprises a broad-band absorptive-type linear polarization structure.

32. The LCD panel construction of claim 31, wherein said broad-band absorptive-type linear polarization structure is operably associated

within said spatial intensity modulation means.

33. The LCD panel construction of claim 31, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spectral filtering means.

34. The LCD panel construction of claim 16, wherein each said spectral filtering element is an optical element made from holographic-type material.

35. The LCD panel construction of claim 16, wherein each said spectral filtering element is an optical element made from interference-type material.

36. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over which spectral components of light are intensity modulated to produce an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis in the direction of a viewer, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum

and each said spectral component of said produced light along said projection axis having a second circular polarization state orthogonal to a first circular polarization state;

spatial intensity modulation means, disposed adjacent said light producing means, for spatial-intensity modulating said distribution of light at each said subpixel region, said spatial intensity modulation means providing each said subpixel region with an intensity modulating element for modulating the intensity of spectral components of said produced light transmitted through said subpixel region so as to produce an intensity level at said subpixel region controlled by a subpixel drive signal associated with said subpixel region; and

spectral filtering means, disposed adjacent said spatial intensity modulation means, for spectral filtering said distribution of produced light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing each said subpixel region with a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region controlled by said subpixel drive signal associated with said subpixel region.

37. The LCD panel construction of claim 36, wherein said light producing means is a backlighting structure comprising:

a light source for producing said spectral components of produced light over said visible band;

a quasi-specular reflector for reflecting spectral components of

produced light and changing, upon reflection, the polarization state thereof from said first circular polarization state to said second circular polarization state and from said second circular polarization state to said first circular polarization state;

a first broad-band circularly polarizing reflective panel for transmitting spectral components of said produced light having said second circular polarization state and reflecting reflecting spectral components of said produced light having said first circular polarization state.

38. The LCD panel construction of claim 37, wherein said backlighting structure further comprises

a light guiding panel for guiding said produced light over said predefined display area.

39. The LCD panel construction of claim 37, wherein said spatial intensity modulation element at each said subpixel region comprises

an electronically-controlled circular polarization state conversion element for converting the polarization stare of said spectral components transmitted through said subpixel region in response to said subpixel driver signal associated with said subpixel.

40. The LCD panel construction of claim 39, wherein each electronically-controlled circular polarization state conversion element comprises a π cell, whose operation is by controlled by said subpixel drive signal associated with said subpixel region.

41. The LCD panel construction of claim 37, wherein said spectral

filtering means comprises:

a second broad-band circularly polarizing reflective panel for reflecting spectral components of said produced light having said first circular polarization state and transmitting spectral components of said produced light having said second circular polarization state; and

a pass-band circularly polarizing reflective element at each said subpixel region for transmitting spectral components of said produced light having said first circular polarization state and spectral components of produced light having wavelengths within said predefined spectral band and said second circular polarization state, and reflecting spectral components of said produced light having wavelengths outside said predefined spectral band and said second circular polarization state.

42. The LCD panel construction of claim 36, wherein said subpixels within each said pixel region comprises:

a "red" subpixel region having a "red" reflective band;

a "green" subpixel region having a "green" reflective band; and

a "blue" subpixel region having a "blue" reflective band.

43. The LCD panel construction of claim 42, wherein said spectral filtering means comprises

a broad-band circularly polarizing reflective panel for reflecting spectral components of said produced light having said second circular polarization state and transmitting spectral components of said produced light having said first circular polarization state;

a first pass-band polarizing reflective element at each said "blue" subpixel region which reflects nearly 100% all spectral

components having said second circular polarization state and a wavelength within said "green" reflective band or said red reflective band, whereas all spectral components having said second circular polarization state or a wavelength within said blue reflective band are transmitted nearly 100% through said pass-band polarizing reflective element;

a second pass-band polarizing reflective element at each said "green" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a wavelength within said red reflective band or said blue reflective band, whereas all spectral components having said second circular polarization state or a wavelength within said green reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "green" subpixel region; and

a third pass-band polarizing reflective element at each said "red" subpixel region which reflects nearly 100% all spectral components having said second circular polarization state and a wavelength within said green reflective band or said blue reflective band, whereas all spectral components having said second circular polarization state or a wavelength within said red reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "red" subpixel region.

44. The LCD panel construction of claim 43, wherein said broad-band circularly polarizing reflective panel comprises a broad-band cholesteric liquid crystal (CLC) panel.

45. The LCD panel construction of claim 43,

wherein said first pass-band polarizing reflective element comprises a first spectrally-tuned CLC element;

wherein said second pass-band polarizing reflective element comprises a second spectrally-tuned CLC element;

wherein said third pass-band polarizing reflective element comprises a third spectrally-tuned CLC element.

46. The LCD panel construction of claim 36, which further comprises

glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

47. The LCD panel construction of claim 46, wherein said glare reduction means comprises a broad-band absorptive-type circular polarization structure.

48. The LCD panel construction of claim 47, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spatial intensity modulation means.

49. The LCD panel construction of claim 47, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spectral filtering means.

50. The LCD panel construction of claim 36, which further comprises

contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

51. The LCD panel construction of claim 50, wherein said contrast

enhancement means comprises a broad-band absorptive-type circular polarization structure.

52. The LCD panel construction of claim 51, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spatial intensity modulation means.

53. The LCD panel construction of claim 52, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spectral filtering means.

54. The LCD panel construction of claim 36, wherein each said spectral filtering element is an optical element made from holographic-type material.

55. The LCD panel construction of claim 36, wherein each said spectral filtering element is an optical element made from interference-type material.

56. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over which spectral components of light are intensity modulated to produce an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis in the direction of a viewer, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum and each said spectral component of said produced light along said projection axis having a second linear polarization state orthogonal to a first linear polarization state;

spectral filtering means, disposed adjacent said light producing means, for spectral filtering said distribution of produced light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing each said subpixel region with a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region controlled by a subpixel drive signal associated with said subpixel region; and

spatial intensity modulation means, disposed adjacent said spectral filtering means, for spatial-intensity modulating said distribution of light at each said subpixel region, said spatial intensity modulation means providing each said subpixel region with an intensity modulating element for modulating the intensity of spectral components of said produced light transmitted through said subpixel region so as to produce an intensity level at said subpixel region controlled by said subpixel drive signal associated with said subpixel region.

57. The LCD panel construction of claim 56, wherein said light producing

means is a backlighting structure comprising:

a light source for producing said spectral components of produced light over said visible band;

a quasi-specular reflector for reflecting spectral components of produced light and changing, upon reflection, the polarization state thereof from said first linear polarization state to said second linear polarization state and from said second linear polarization state to said first linear polarization state;

a first broad-band linearly polarizing reflective panel for transmitting spectral components of said produced light having said second linear polarization state and reflecting reflecting spectral components of said produced light having said first linear polarization state.

58. The LCD panel construction of claim 57, wherein said backlighting structure further comprises a light guiding panel for guiding said produced light over said predefined display area.

59. The LCD panel construction of claim 57, wherein said spatial intensity modulation element at each said subpixel region comprises:

an electronically-controlled linear polarization direction rotating element for rotating the polarization direction of said spectral components transmitted through said subpixel region in response to said subpixel driver signal associated with said subpixel; and

a second broad-band linearly polarizing reflective panel for reflecting spectral components of said produced light having said second linear polarization state and transmitting spectral components of said produced light having said first linear polarization state.

60. The LCD panel construction of claim 59, wherein each electronically-controlled linear polarization rotating element comprises a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by said subpixel drive signal associated with said subpixel region.

61. The LCD panel construction of claim 56, wherein said spectral filtering means comprises:

a pass-band polarizing reflective element at each said subpixel region for transmitting spectral components of said produced light having said second linear polarization state and spectral components of produced light having wavelengths within said predefined spectral band, and reflecting spectral components of said produced light having wavelengths outside said predefined spectral band and said second linear polarization state.

62. The LCD panel construction of claim 56, wherein said subpixels within each said pixel region comprises:

a "red" subpixel region having a "red" reflective band;
a "green" subpixel region having a "green" reflective band; and
a "blue" subpixel region having a "blue" reflective band.

63. The LCD panel construction of claim 62, wherein said spectral filtering means comprises:

a first pass-band polarizing reflective element at each said "blue" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a

wavelength within said "green" reflective band or said red reflective band, whereas all spectral components having said second linear polarization state and a wavelength within said blue reflective band are transmitted nearly 100% through said pass-band polarizing reflective element;

a second pass-band polarizing reflective element at each said "green" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a wavelength within said red reflective band or said blue reflective band, whereas all spectral components having said second polarization state and a wavelength within said green reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "green" subpixel region; and

a third pass-band polarizing reflective element at each said "red" subpixel region which reflects nearly 100% all spectral components having said second linear polarization state and a wavelength within said green reflective band or said blue reflective band, whereas all spectral components having said second linear polarization state and a wavelength within said red reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "red" subpixel region.

64. The LCD panel construction of claim 63, wherein said broad-band linearly polarizing reflective panel comprises a broad-band cholesteric liquid crystal (CLC) panel and a broad-band $\pi/2$-phase retardation structure.

65. The LCD panel construction of claim 63,

wherein said first broad-band linearly polarizing reflective panel comprises a first broad-band cholesteric liquid crystal (CLC) panel and a first broad-band $\pi/2$-phase retardation structure; and

wherein said second broad-band linearly polarizing reflective panel comprises a second broad-band cholesteric liquid crystal (CLC) panel and a second broad-band $\pi/2$-phase retardation structure.

66. The LCD panel construction of claim 63,

wherein said first pass-band polarizing reflective element comprises a first spectrally-tuned CLC element and a $\pi/2$-phase retardation structure;

wherein said second pass-band polarizing reflective element comprises a second spectrally-tuned CLC element and a $\pi/2$-phase retardation structure;

wherein said third pass-band polarizing reflective element comprises a third spectrally-tuned CLC element and a $\pi/2$-phase retardation structure.

67. The LCD panel construction of claim 56, which further comprises

glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

68. The LCD panel construction of claim 67, wherein said glare reduction means comprises a broad-band absorptive-type linear polarization structure.

69. The LCD panel construction of claim 68, wherein said broad-band

absorptive-type linear polarization structure is operably associated within said spatial intensity modulation means.

70. The LCD panel construction of claim 69, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spectral filtering means.

71. The LCD panel construction of claim 56, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

72. The LCD panel construction of claim 71, wherein said contrast enhancement means comprises a broad-band absorptive-type linear polarization structure.

73. The LCD panel construction of claim 72, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spatial intensity modulation means.

74. The LCD panel construction of claim 73, wherein said broad-band absorptive-type linear polarization structure is operably associated within said spectral filtering means.

75. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over

which spectral components of light are intensity modulated to produce an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis in the direction of a viewer, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum and each said spectral component of said produced light along said projection axis having a second circular polarization state orthogonal to a first circular polarization state;

spectral filtering means, disposed adjacent said light producing means, for spectral filtering said distribution of produced light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing each said subpixel region with a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region controlled by a subpixel drive signal associated with said subpixel region; and

spatial intensity modulation means, disposed adjacent said spatial intensity modulation means, for spatial-intensity modulating said distribution of light at each said subpixel region, said spatial intensity modulation means providing each said subpixel region with an intensity modulating element for modulating the intensity of spectral components of said produced light transmitted through said subpixel

region so as to produce an intensity level at said subpixel region controlled by said subpixel drive signal associated with said subpixel region.

76. The LCD panel construction of claim 75, wherein said light producing means is a backlighting structure comprising:

a light source for producing said spectral components of produced light over said visible band;

a quasi-specular reflector for reflecting spectral components of produced light and changing, upon reflection, the polarization state thereof from said first circular polarization state to said second circular polarization state and from said second circular polarization state to said first circular polarization state;

a first broad-band circularly polarizing reflective panel for transmitting spectral components of said produced light having said second circular polarization state and reflecting reflecting spectral components of said produced light having said first circular polarization state.

77. The LCD panel construction of claim 76, wherein said backlighting structure further comprises a light guiding panel for guiding said produced light over said predefined display area.

78. The LCD panel construction of claim 76, wherein said spatial intensity modulation element at each said subpixel region comprises:

an electronically-controlled circular polarization state conversion element for converting the polarization state of said spectral components transmitted through said subpixel region in response to

said subpixel driver signal associated with said subpixel; and

a second broad-band circularly polarizing reflective panel for reflecting spectral components of said produced light having said second circular polarization state and transmitting spectral components of said produced light having said first circular polarization state.

79. The LCD panel construction of claim 78, wherein each electronically-controlled circular polarization state conversion element comprises a π cell, whose operation is by controlled by said subpixel drive signal associated with said subpixel region.

80. The LCD panel construction of claim 75, wherein said spectral filtering means comprises:

a pass-band polarizing reflective element at each said subpixel region for transmitting spectral components of said produced light having said second circularly polarization state and spectral components of produced light having wavelengths within said predefined spectral band, and reflecting spectral components of said produced light having wavelengths outside said predefined spectral band and said second circular polarization state.

81. The LCD panel construction of claim 75, wherein said subpixels within each said pixel region comprises:

a "red" subpixel region having a "red" reflective band;

a "green" subpixel region having a "green" reflective band; and

a "blue" subpixel region having a "blue" reflective band.

82. The LCD panel construction of claim 81, wherein said spectral

filtering means comprises:

a first pass-band polarizing reflective element at each said "blue" subpixel region which reflects nearly 100% all spectral components having said second circular polarization state and a wavelength within said "green" reflective band or said red reflective band, whereas all spectral components having said second circular polarization state and a wavelength within said blue reflective band are transmitted nearly 100% through said pass-band polarizing reflective element;

a second pass-band polarizing reflective element at each said "green" subpixel region which reflects nearly 100% all spectral components having said second circular polarization state and a wavelength within said red reflective band or said blue reflective band, whereas all spectral components having said second circular polarization state and a wavelength within said green reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "green" subpixel region; and

a third pass-band polarizing reflective element at each said "red" subpixel region which reflects nearly 100% all spectral components having said second circular polarization state and a wavelength within said green reflective band or said blue reflective band, whereas all spectral components having said second circular polarization state and a wavelength within said red reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "red" subpixel region.

83. The LCD panel construction of claim 76, wherein said broad-band circularly polarizing reflective panel comprises a broad-band cholesteric

liquid crystal (CLC) panel.

84. The LCD panel construction of claim 82,

wherein said first broad-band linearly polarizing reflective panel comprises a first broad-band cholesteric liquid crystal (CLC) panel; and

wherein said second broad-band linearly polarizing reflective panel comprises a second broad-band cholesteric liquid crystal (CLC) panel.

85. The LCD panel construction of claim 82,

wherein said first pass-band polarizing reflective element comprises a first spectrally-tuned CLC element;

wherein said second pass-band polarizing reflective element comprises a second spectrally-tuned CLC element;

wherein said third pass-band polarizing reflective element comprises a third spectrally-tuned CLC element.

86. The LCD panel construction of claim 75, which further comprises

glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

87. The LCD panel construction of claim 86, wherein said glare reduction means comprises a broad-band absorptive-type circular polarization structure.

88. The LCD panel construction of claim 87, wherein said broad-band absorptive-type circular polarization structure is operably associated

within said spatial intensity modulation means.

89. The LCD panel construction of claim 88, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spectral filtering means.

90. The LCD panel construction of claim 75, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

91. The LCD panel construction of claim 90, wherein said contrast enhancement means comprises a broad-band absorptive-type circular polarization structure.

92. The LCD panel construction of claim 91, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spatial intensity modulation means.

93. The LCD panel construction of claim 92, wherein said broad-band absorptive-type circular polarization structure is operably associated within said spectral filtering means.

94. A liquid crystal display (LCD) panel construction for producing color images from a plurality of pixel regions within a predefined display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a predefined spectral band along the electromagnetic spectrum over which spectral components of light are intensity modulated to produce

an intensity level at said subpixel region and spectrally filtered to produce a color value at said subpixel region, whereby said color images are produced, said LCD panel construction comprising:

light producing means for producing a distribution of light confined within said predefined surface area and projected along a projection axis in the direction of a viewer, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum and each said spectral component of said produced light along said projection axis having a second polarization state orthogonal to a first polarization state;

spatial intensity modulation means for spatial-intensity modulating said distribution of light at each said subpixel region, said spatial intensity modulation means providing each said subpixel region with an intensity modulating element for modulating the intensity of spectral components of said produced light transmitted through said subpixel region so as to produce an intensity level at said subpixel region controlled by a subpixel drive signal associated with said subpixel region; and

spectral filtering means for spectral filtering said distribution of produced light at each said subpixel region in accordance with said plurality of subpixel drive signals, said spectral filtering means providing each said subpixel region with a spectral filtering element for transmitting only spectral components of said produced light having wavelengths within said predefined spectral band and reflecting spectral components of produced light having wavelengths outside said predefined spectral band so as to produce a color value at said subpixel region controlled by said subpixel drive signal associated with said

subpixel region.

95. The LCD panel construction of claim 94, wherein said light producing means is a backlighting structure comprising:

a light source for producing said spectral components of produced light over said visible band;

a quasi-specular reflector for reflecting spectral components of produced light and changing, upon reflection, the polarization state thereof from said first polarization state to said second polarization state and from said second polarization state to said first polarization state;

a first broad-band reflective panel for transmitting spectral components of said produced light having said second polarization state and reflecting reflecting spectral components of said produced light having said first polarization state.

96. The LCD panel construction of claim 94, wherein said backlighting structure further comprises

a light guiding panel for guiding said produced light over said predefined display area.

97. The LCD panel construction of claim 95, wherein said spatial intensity modulation element at each said subpixel region comprises

an electronically-controlled polarization state conversion element for converting the polarization state of said spectral components transmitted through said subpixel region in response to said subpixel driver signal associated with said subpixel.

98. The LCD panel construction of claim 97, wherein each electronically-

controlled polarization state conversion element comprises a twisted nematic (TN) liquid crystal cell, super-twisted nematic (STN) liquid crystal cell, or ferro-electric cell, whose operation is by controlled by said subpixel drive signal associated with said subpixel region.

99. The LCD panel construction of claim 95, wherein said spectral filtering means comprises:

a second broad-band reflective panel for reflecting spectral components of said produced light having said first polarization state and transmitting spectral components of said produced light having said second polarization state; and

a pass-band reflective element at each said subpixel region for transmitting spectral components of said produced light having said first polarization state and spectral components of produced light having wavelengths within said predefined spectral band and said second polarization state, and reflecting spectral components of said produced light having wavelengths outside said predefined spectral band and said second polarization state.

100. The LCD panel construction of claim 94, wherein each said subpixel region produces a “dark” output level when said pixel driver signal provided thereto is a first control voltage signal, and each said subpixel region produces a “bright” output level when said pixel driver signal provided thereto is a second control voltage signal.

101. The LCD panel construction of claim 94, wherein said subpixels within each said pixel region comprises:

a “red” subpixel region having a “red” reflective band;

a "green" subpixel region having a "green" reflective band; and a "blue" subpixel region having a "blue" reflective band.

102. The LCD panel construction of claim 94, wherein said spectral filtering means comprises

a broad-band polarizing panel for absorbing spectral components of said produced light having said second polarization state and transmitting spectral components of said produced light having said first polarization state,

whereby ambient light comprising spectral components having wavelengths over said visible band and said second polarization state are absorbed at said broad-band polarizing panel, while ambient light comprising spectral components having wavelengths over said visible band and said first polarization state are transmitted through said broad-band linearly polarizing panel and recycled within said light producing means, thereby reducing glare associated with said ambient light.

103. The LCD panel construction of claim 94, wherein said spectral filtering means comprises

a broad-band polarizing reflective panel for reflecting spectral components of said produced light having said second polarization state and transmitting spectral components of said produced light having said first polarization state.

104. The LCD panel construction of claim 103, wherein said spectral filtering means comprises:

a first pass-band reflective element at each said "blue" subpixel

region which reflects nearly 100% all spectral components having said second polarization state and a wavelength within said "green" reflective band or said red reflective band, whereas all spectral components having said second polarization state or a wavelength within said blue reflective band are transmitted nearly 100% through said pass-band polarizing reflective element;

a second pass-band reflective element at each said "green" subpixel region which reflects nearly 100% all spectral components having said second polarization state and a wavelength within said red reflective band or said blue reflective band, whereas all spectral components having said second polarization state or a wavelength within said green reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "green" subpixel region; and

a third pass-band reflective element at each said "red" subpixel region which reflects nearly 100% all spectral components having said second polarization state and a wavelength within said green reflective band or said blue reflective band, whereas all spectral components having said second polarization state or a wavelength within

said red reflective band are transmitted nearly 100% through said pass-band polarizing reflective element at each said "red" subpixel region.

105. The LCD panel construction of claim 94, which further comprises glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

106. The LCD panel construction of claim 105, wherein said glare reduction means comprises broad-band absorptive-type polarizating material.

107. The LCD panel construction of claim 106, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

108. The LCD panel construction of claim 107, wherein said broad-band absorptive-type polarizing material is operably associated with said spectral filtering means.

109. The LCD panel construction of claim 94, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

110. The LCD panel construction of claim 109, wherein said contrast enhancement means comprises broad-band absorptive-type polarizing material.

111. The LCD panel construction of claim 110, wherein said broad-band

absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

112. The LCD panel construction of claim 111, wherein said broad-band absorptive-type polarization structure is operably associated with said spectral filtering means.

113. The LCD panel construction of claim 94, wherein each said spectral filtering element is an optical element made from holographic-type material.

114. The LCD panel construction of claim 94, wherein each said spectral filtering element is an optical element made from interference-type material.

115. A color LCD panel employing a novel scheme of systemic light recycling which operates at all levels of the LCD system in order substantially reduce internal light energy losses and allow at least 50% of the light energy produced by the backlighting structure to be used to produce color images from said color LCD panel.

116. The color LCD panel of Claim 115, wherein a single polarization state of light is transmitted from the backlighting structure to section of the LCD panel where both spatial intensity and spectral filtering of the transmitted polarized light simultaneously occurs on a subpixel basis, in a functionally integrated manner.

117. The color LCD panel of claim 115, wherein at each subpixel

location therein, spectral bands of light which are not transmitted to the display surface during spectral filtering, are reflected without absorption back along its projection axis into the backlighting structure where the polarized light is recycled with light energy being generated therewith and then retransmitted from the backlighting structure into section of the LCD panel where spatial intensity modulation and spectral filtering of the retransmitted polarized light simultaneously occurs on a subpixel basis in a functionally integrated manner.

118. The color LCD panel of claim 115, at each subcomponent level within the LCD panel, spectral components of transmitted polarized light which are not used at any particular subpixel structure location are effectively reflected either directly or indirectly back into the backlighting structure for systemic recycling with other spectral components for retransmission through the backlighting structure at the operative polarization state, for reuse by neighboring subpixel structures.

119. A color LCD panel capable of producing high brightness color images, which comprises:

light producing means for producing a distribution of light having spectral components over the visible band, and a substantially uniform spatial intensity over a predefined display region;

spatial intensity modulation means for modulating the spatial intensity of said distribution of light produced from said light producing means, so as to form an image;

spectral filtering means for spectrally filtering said distribution of light to image color characteristics to said image; and

light recycling means for systemically recycling spectral components of light produced said light producing means, said light recycling means cooperating with said light producing means, said spatial intensity modulation means and said spectral filtering means during the display of color images from said color LCD panel.

120. The color LCD panel of claim 119, wherein the spatial-intensity modulation and spectral filtering functions associated with each subpixel structure of the LCD panel are realized at a different location along the x and y axes thereof.

121. The color LCD panel of claim 119, wherein the spatial-intensity modulation and spectral filtering functions associated with each and every subpixel structure of the LCD panel are carried out without absorbing or dissipating any of the spectral energy produced from the backlighting structure during color image production.

122. The color LCD panel of claim 119, wherein the spatial-intensity modulation and spectral filtering functions associated with each and every subpixel structure of the LCD panel are carried out using the polarization/wavelength dependent transmission and reflection properties of CLC-based filters.

123. The color LCD panel construction of claim 119, which further comprises

glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel construction.

124. The color LCD panel construction of claim 123, wherein said glare reduction means comprises broad-band absorptive-type polarizating material.

125. The color LCD panel construction of claim 124, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

126. The color LCD panel construction of claim 122, wherein said broad-band absorptive-type polarizing material is operably associated with said spectral filtering means.

127. The color LCD panel construction of claim 119, which further comprises

contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

128. The color LCD panel construction of claim 127, wherein said contrast enhancement means comprises broad-band absorptive-type polarizing material.

129. The color LCD panel construction of claim 128, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

130. The color LCD panel construction of claim 128, wherein said broad-band absorptive-type polarization structure is operably associated with said spectral filtering means.

131. The color LCD panel construction of claim 123, wherein each said spectral filtering means comprises a plurality of optical elements made from holographic-type material.

132. The color LCD panel construction of claim 119, wherein each said spectral filtering means comprises an optical element made from interference-type material.

133. A method of displaying color images from a color LCD panel, comprising the steps of:

(a) producing within said color LCD panel, a distribution of light having spectral components over the visible band, and a substantially uniform spatial intensity over a predefined display region;

(b) modulating within said color LCD panel, the spatial intensity of said distribution of light produced from said light producing means, so as to form an image;

(c) within said color LCD panel, spectrally filtering said distribution of light to image color characteristics to said image; and

(d) within said color LCD panel, systemically recycling spectral components of said produced during steps (a), (b) and (c) above.

134. A method of making a color LCD panel, which comprises:

(a) forming a panel having an array of reflective spectral filters for each subpixel in said color LCD panel; and

(b) forming a patterned broad-band polarizing reflective region between the reflective spectral filters of said array, for reflecting incident polarized light of predetermined polarization state to improve

image contrast and light transmission efficiency of said color LCD panel.

135. A color image projection system, comprising:

a system housing;

an LCD panel;

a plurality of conventional backlighting structures cascaded together and mounted to the rear portion of said LCD panel in order to provide an LCD panel assembly that can be mounted within the display portion of the system housing and project bright images onto a remote surface without the use of an external light source or a rear opening in the display portion of the housing, for projecting light therethrough during its projection-viewing mode of operation.

136. A liquid crystal display (LCD) panel for producing color images, comprising:

backlighting means for producing a distribution of light over the visible band;

broad-band polarizing means, of the non-absorptive type, for polarizing said produced light;

light intensity modulation means for modulating the spatial intensity of said produced polarized light so as to form an image;

spectral filtering means, of the non-absorptive type, for spectrally filtering said produced light so as to form impart color characterisics to said image thereby forming a color image; and

systemic light recycling means, cooperating among said backlighting means, said broad-band polarizing means, and spectral filtering means and said light intensity modulation means, for recycling produced light within said LCD panel so as to enhance the brightness of

said color image.

137. The LCD panel of claim 136, which further comprises glare reduction means for reducing glare produced as a result of ambient light falling incident on said LCD panel.

138. The LCD panel of claim 137, wherein said glare reduction means comprises broad-band absorptive-type polarizating material.

139. The LCD panel of claim 138, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

140. The LCD panel of claim 139, wherein said broad-band absorptive-type polarizing material is operably associated with said spectral filtering means.

141. The LCD panel of claim 136, which further comprises contrast enhancement means for enhancing the contrast of images produced from said predefined image display area.

141. The LCD panel of claim 140, wherein said contrast enhancement means comprises broad-band absorptive-type polarizing material.

142. The color LCD panel of claim 141, wherein said broad-band absorptive-type polarizing material is operably associated with said spatial intensity modulation means.

143. The LCD panel construction of claim 142, wherein said broad-band absorptive-type polarization structure is operably associated with said spectral filtering means.

144. The color LCD panel construction of claim 136, wherein said spectral filtering means comprises a plurality of optical elements made from holographic-type material.

145. The color LCD panel construction of claim 136, wherein said spectral filtering means comprises an optical element made from interference-type material.

146. The color LCD panel construction of claim 136, wherein said broad-band polarizing means comprises an optical element made from holographic-type material.

147. The color LCD panel construction of claim 136, wherein said broad-band polarizing means comprises an optical element made from interference-type material.

148. The color LCD panel construction of claim 1, wherein said light intensity modulation means comprises a broad-band polarizing panel.

149. The color LCD panel construction of claim 148, wherein said broad-band polarizing panel comprises an optical element made from broad-band holographic-type material.

150. The color LCD panel construction of claim 148, wherein said broad-

band polarizing panel comprises an optical element made from broad-band interference-type material.

151. A backlighting structure for use in an LCD panel, comprising:

a light source for producing a distribution of light confined within a predefined surface area and projected along a projection axis, said distribution of light consisting of spectral components of light having wavelengths over a substantial portion of the visible band of said electromagnetic spectrum and each said spectral component of said produced light along said projection axis having a predetermined polarization state;

a quasi-specular reflector for reflecting spectral components of produced light and changing, upon reflection, the polarization state thereof from a first polarization state to a second linear polarization state and from said second polarization state to said first polarization state;

a first broad-band polarizing reflective panel for transmitting spectral components of said produced light having said second polarization state and reflecting reflecting spectral components of said produced light having said first polarization state.

152. The LCD panel construction of claim 151, wherein said backlighting structure further comprises

a light guiding panel for guiding said produced light over said predefined display area.

153. The backlighting structure of claim 151, wherein said first polarization state is a first linear polarization state and said said second

polarization state is a second linear polarization state.

154. The backlighting structure of claim 151, wherein said first polarization state is a left-handed circular polarization state and said said second polarization state is a right-handed polarization state.

155. A computer-controlled system for fabricating a pixelated pass-band polarizing reflective panel for use in an LCD panel, said computer-controlled system comprising:

a fixture for supporting a plate the size of the LCD panel to be fabricated, within the x-y plane of a coordinate reference frame embedded within the system;

coating means for coating one surface of the plate with a CLC mixture to produce a CLC-coated plate;

a temperature-controlled oven, within which said CLC coated plate can be transported and maintained for optical and/or thermal processing;

a subpixel-exposure mask having a pattern of apertures which spatially correspond with the red, green or blue subpixel structures, respectively, of the LCD panel to be fabricated;

a subpixel-array mask having a pattern of opaque subpixel regions which spatially correspond with the red, green or blue subpixel structures of the LCD panel to be fabricated;

a mask translator for precisely translating said masks relative to said fixture along the x and y axes of the system;

a source of ultraviolet (UV) radiation for producing a focused beam of UV radiation having a specified bandwidth, for exposing the layer of CLC material upon said plate supported within said fixture,

while said CLC layer is precisely maintained at a preselected temperature;

a temperature controller for controlling the temperature of the interior of said oven and thus said layer of CLC material coated on said plate; and

a system controller for controlling the operation of said mask translator and said temperature controller during fabrication of said pixelated pass-band polarizing reflective panel.

156. The computer-controlled system of claim 155 wherein said CLC mixture contains in its liquid phase, liquid crystals, monomers, and other additives.

157. The computer-controlled system of claim 156, wherein said temperature-controlled oven has a UV transparent window.

158. A method of fabricating a spectral filtering panel for use in an LCD panel, said method comprising the steps of:

(a) applying a layer of CLC-mixture onto the surface of an optically-transparent support substrate having length and width dimensions equal to the size of the LCD panel to be fabricated;

(b) loading said CLC-coated plate into a temperture-controlled oven;

(c) translating a subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation, so as to form an array of pass-band polarizing reflective elements tuned to the blue spectral-band $\Delta\lambda_B$;

(d) exposing said CLC-coated plate to UV light through the mask positioned for forming pass-band polarizing reflective elements

tuned to the blue spectral-band $\Delta\lambda_B$;

(e) translating said subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation so as to form an array of pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$;

(f) allowing said CLC coated plate to reach a first preselected temperature;

(g) exposing the CLC-coated plate to UV light through said subpixel-exposure mask positioned for forming pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$;

(h) translating said subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation to form an array of pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$;

(i) allowing said CLC coated plate is allowed to reach a second preselected temperature;

(j) exposing said CLC-coated plate to UV light through said subpixel-exposure mask positioned for forming pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$;

(k) removing the subpixel-exposure mask and installing a pixel-array mask above said CLC-coated plate;

(l) adjusting said temperture-controlled oven temperature allowing and said CLC-coated plate to attain a third predetermined temperature so that broad-band polarizing reflection characteristics will be imparted to the CLC-coating over those unprotected regions determined by said pixel-array mask mask;

(m) setting the intensity of the UV light to a predetermined

value required to achieve broad-band operation using said CLC-mixture at said predetermined exposure temperature;

(n) exposing the CLC-coated plate to the UV light at said intensity and said temperature to form a broad-band polaring reflective region between the interstices of the subpixel filter elements formed on said CLC-coated plate; and

(o) removing said exposed CLC-coated plate from said oven and allow to cool to room temperature, thereby producing a spectral filtering panel having three spatially arranged arrays of pass-band circularly-polarizing reflective elements with a polarizing reflective matrix-mask region formed therebetween.

159. Apparatus for fabricating a spectral filtering panel for use in an LCD panel, said apparatus comprising:

means for applying a layer of CLC-mixture onto the surface of an optically-transparent support substrate having length and width dimensions equal to the size of the LCD panel to be fabricated;

means for loading said CLC-coated plate into a temperture-controlled oven;

means for translating a subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation, so as to form an array of pass-band polarizing reflective elements tuned to the blue spectral-band $\Delta\lambda_B$;

means for exposing said CLC-coated plate to UV light through the mask positioned for forming pass-band polarizing reflective elements tuned to the blue spectral-band $\Delta\lambda_B$;

means for translating said subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation so as to

form an array of pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$;

means for allowing said CLC coated plate to reach a first preselected temperature;

means for exposing the CLC-coated plate to UV light through said subpixel-exposure mask positioned for forming pass-band polarizing reflective elements tuned to the green spectral-band $\Delta\lambda_G$;

means for translating said subpixel-exposure mask into position over said CLC-coated plate for exposure to UV radiation to form an array of pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$;

means for allowing said CLC coated plate is allowed to reach a second preselected temperature;

means for exposing said CLC-coated plate to UV light through said subpixel-exposure mask positioned for forming pass-band polarizing reflective elements tuned to the red spectral-band $\Delta\lambda_R$;

means for removing the subpixel-exposure mask and installing a pixel-array mask above said CLC-coated plate;

means for adjusting said temperture-controlled oven temperature allowing and said CLC-coated plate to attain a third predetermined temperature so that broad-band polarizing reflection characteristics will be imparted to the CLC-coating over those unprotected regions determined by said pixel-array mask mask;

means for setting the intensity of the UV light to a predetermined value required to achieve broad-band operation using said CLC-mixture at said predetermined exposure temperature;

means for exposing the CLC-coated plate to the UV light at said

intensity and said temperature to form a broad-band polaring reflective region between the interstices of the subpixel filter elements formed on said CLC-coated plate; and

means for removing said exposed CLC-coated plate from said oven and allow to cool to room temperature, thereby producing a spectral filtering panel having three spatially arranged arrays of pass-band circularly-polarizing reflective elements with a polarizing reflective matrix-mask region formed therebetween.

160. A liquid crystal display (LCD) panel construction for producing color images for viewing by a viewer, said LCD panel comprising:

a plurality of pixel regions within a predefined image display area, wherein each said pixel region has a plurality of subpixel regions and each said subpixel region within each said pixel region has a light transmission portion and a light blocking portion, and each said light transmission portion and said light blocking portion having a frontside disposed in the direction of said viewer and a backside in the direction of said illumination means;

illumination means for illuminating said plurality of pixel regions from the backside thereof so that a color image is formed from said plurality of pixel regions for viewing;

a pattern of broad-band reflector material, in spatial registration with the backside of said light blocking portions of said subpixel regions, for reflecting produced light at structures associated with said light blocking portions of the subpixels and thereby recycling produced light for use in illuminating said plurality of pixel regions; and

a pattern of broad-band absorption material, in spatial registration with the frontside of said light blocking portions of said

subpixel regions, for absorbing ambient light incident upon structures associated with said light blocking portions of said subpixels and thereby reducing glare at the surface of the LCD panel due to ambient light incident thereon.

161. The LCD panel of claim 160, wherein said broad-band reflector material is a broad-band reflector.

162. The LCD panel of claim 160, wherein said broad-band absorption material is a broad-band absorber.

105-016 PCT

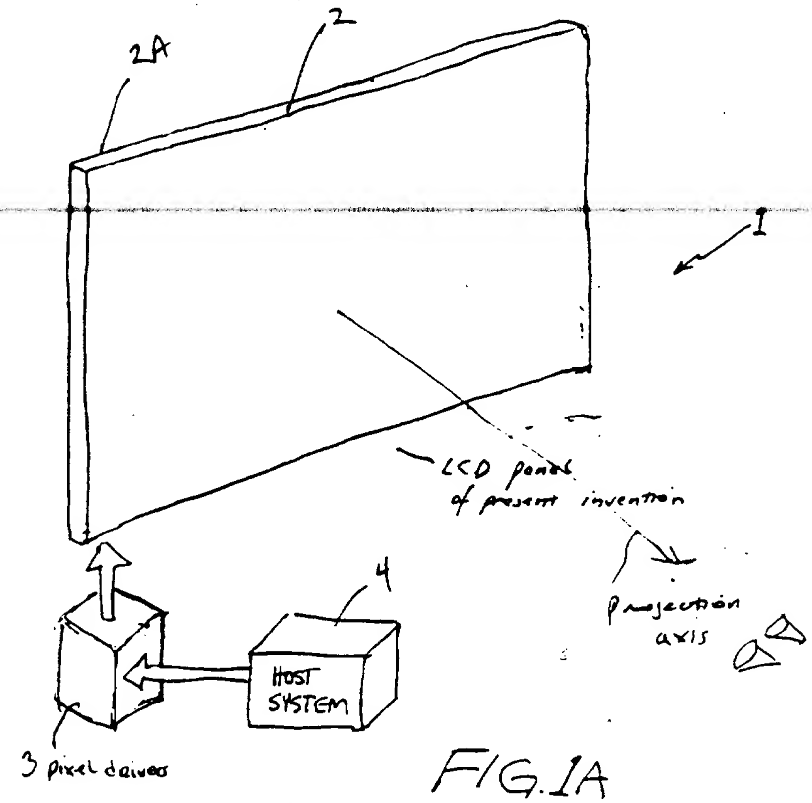

FIG. 1A

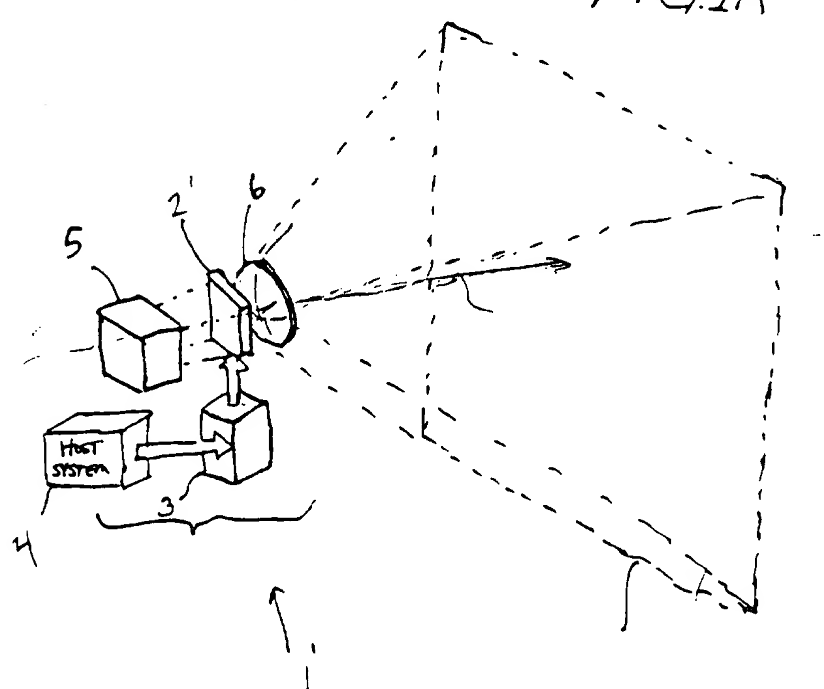

FIG 1B

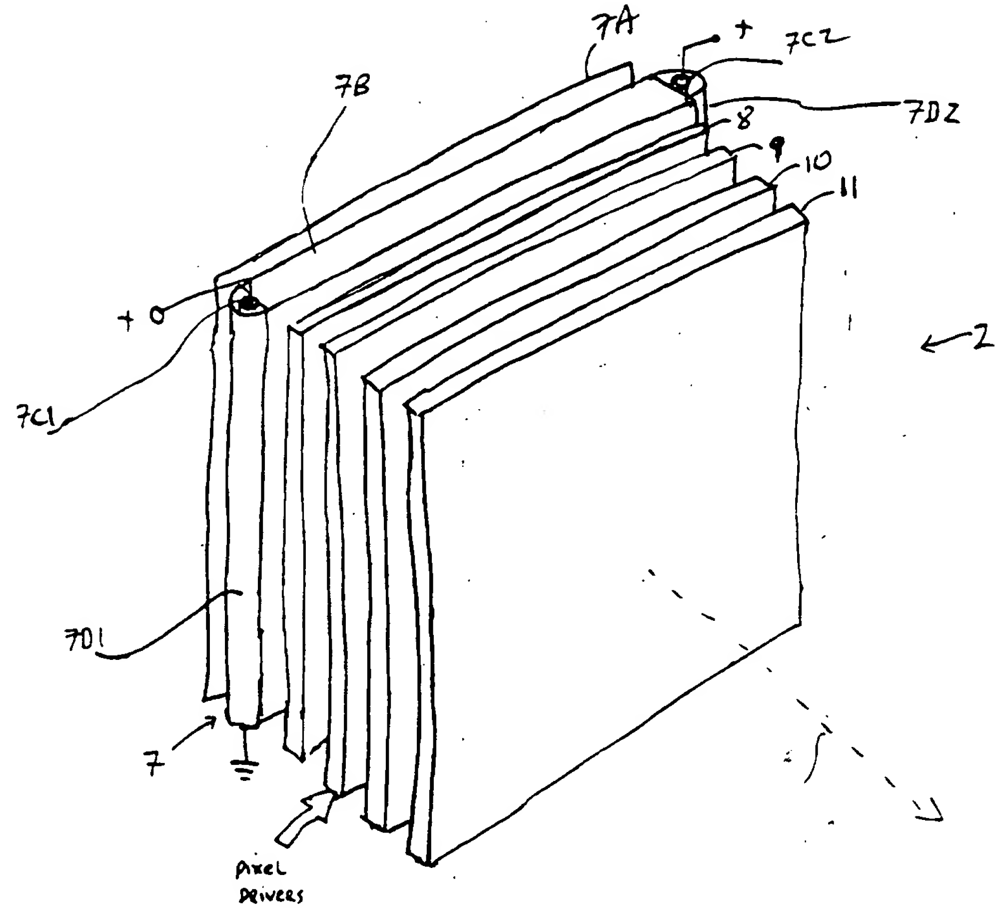
7A
+
7C2
7B
7D2
8
9
10
11
+
7C1
2
7D1
7
PIXEL DRIVERS

FIG. 2

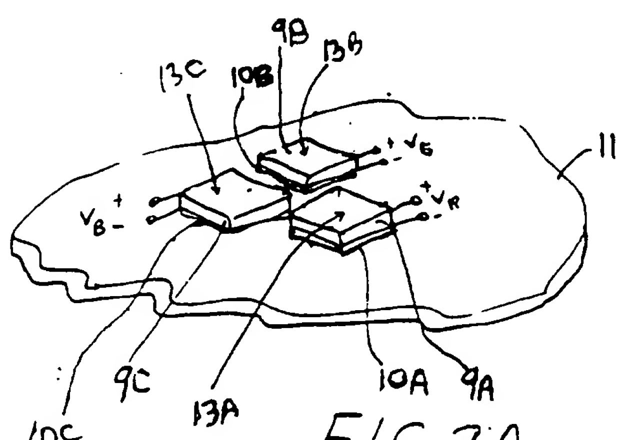
9B
13B
13C
10B
11
V_G
V_B
V_R
10C
9C
13A
10A
9A

FIG. 2A

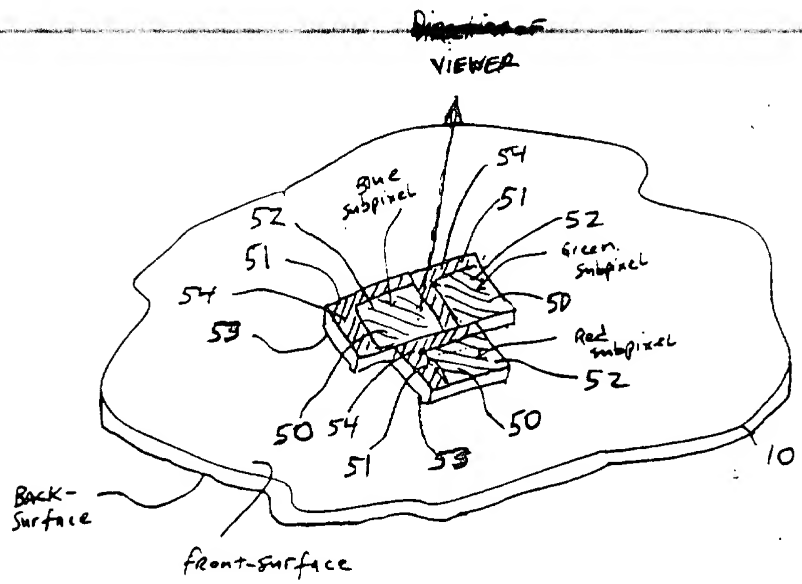
VIEWER
Blue subpixel
Green subpixel
Red subpixel
54
51
52
50
53
10
Back-Surface
front-surface

FIG. 2B

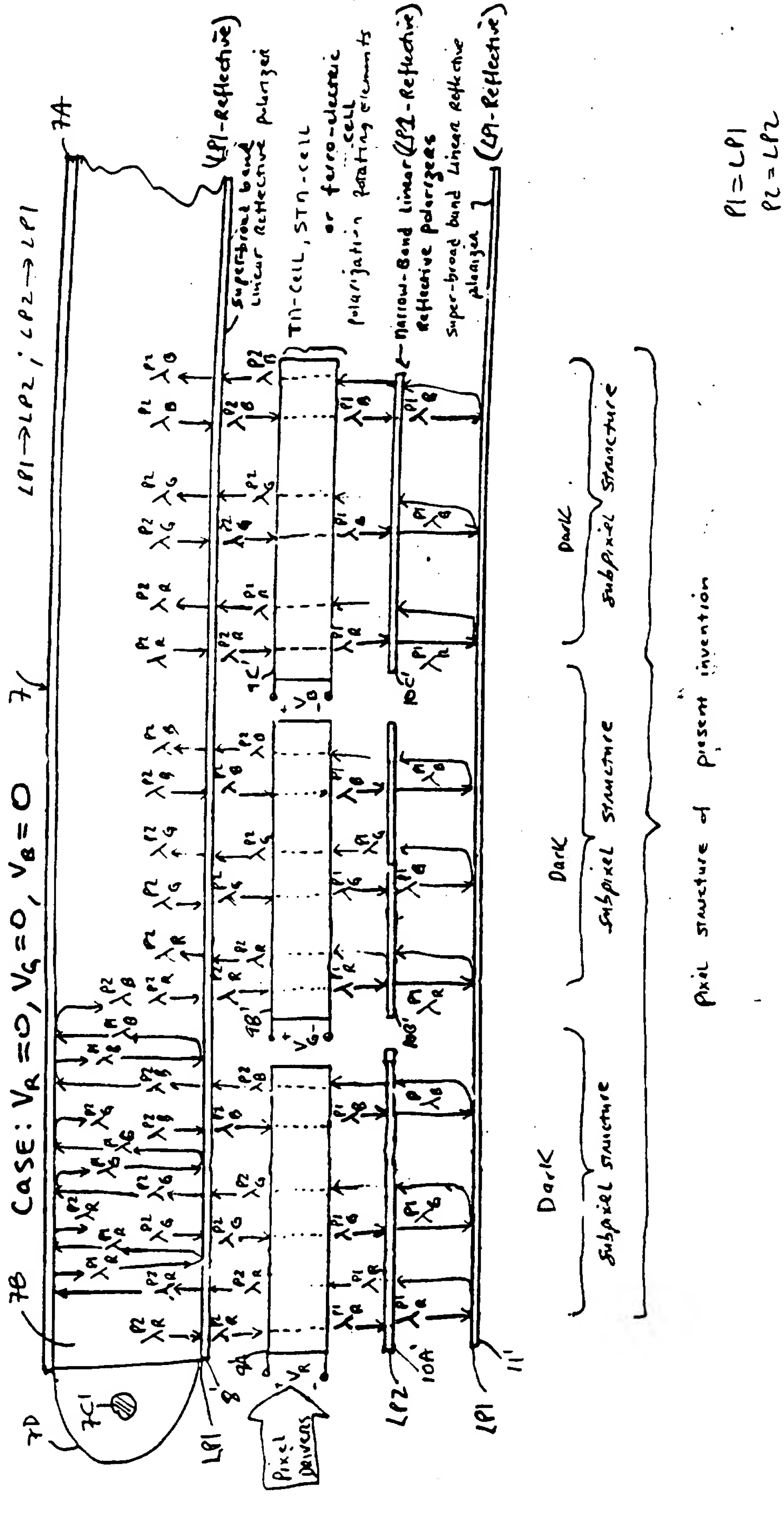
CASE: V_R=0, V_G=0, V_B=0
LP1→LP2; LP2→LP1
LP1-Reflective
Super-broad band Linear Reflective polarizer
TN-cell, STN-cell or ferro-electric cell polarization rotating elements
Narrow-Band linear (LP2-Reflective) Reflective polarizers
Super-broad band Linear Reflective polarizer
(LP1-Reflective)
Dark
Subpixel structure
Pixel structure of present invention
Pixel Drivers
LP1
LP2
P1=LP1
P2=LP2

FIG. 3A1

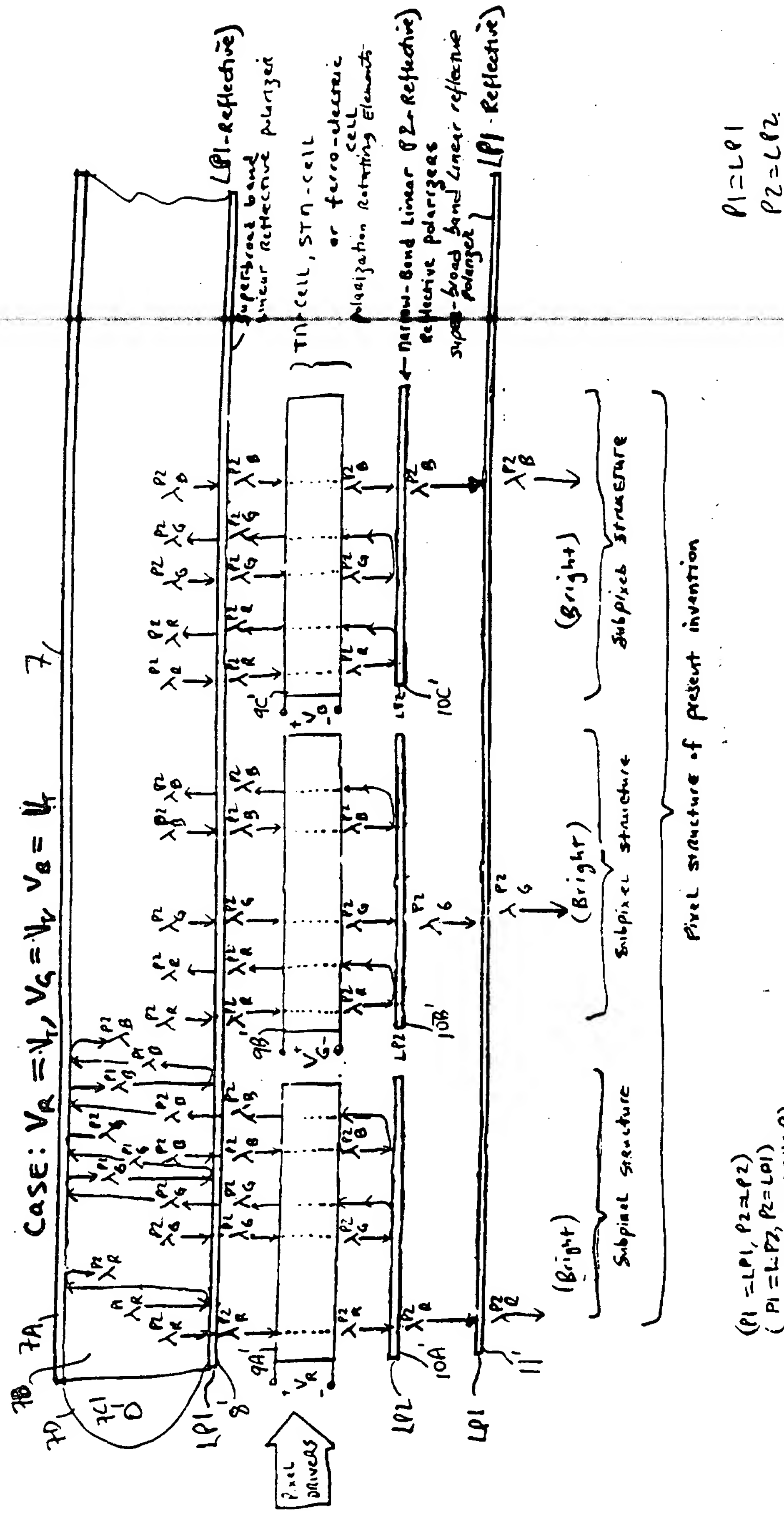
CASE: VR = VT, VG = VT, VB = VT
LP1-Reflective
Superbroad band Linear Reflective polarizer
TN cell, STN-cell or ferro-electric cell
Polarization Rotating Elements
Narrow-Band Linear (P2-Reflective) Reflective polarizers
Super-broad band Linear reflective polarizer
LP1-Reflective
(Bright)
Subpixel Structure
Pixel structure of present invention
Pixel DRIVERS
P1=LP1
P2=LP2
(P1=LP1, P2=LP2)
(P1=LP2, P2=LP1)
(P1=LHCP, P2=RHCP)
(P1=RHCP, P2=LHCP)

FIG. 3A2

FIG 3B

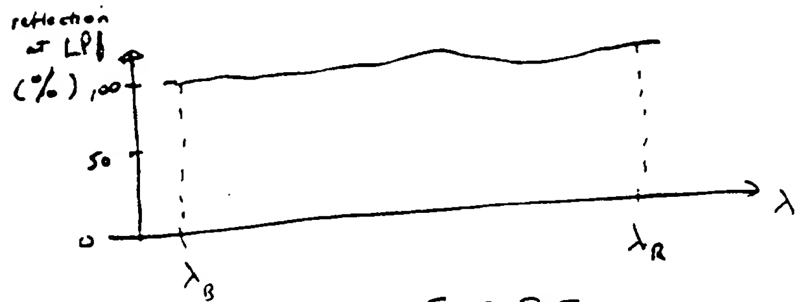

FIG 3C

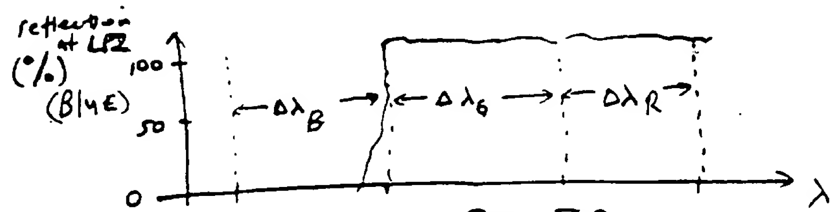

FIG. 3D

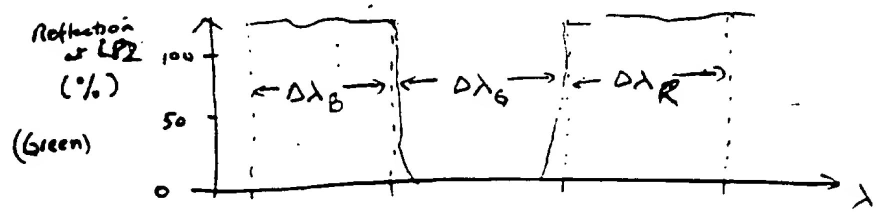

FIG. 3E

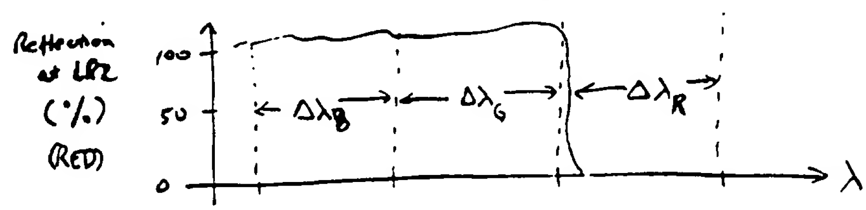

FIG. 3F

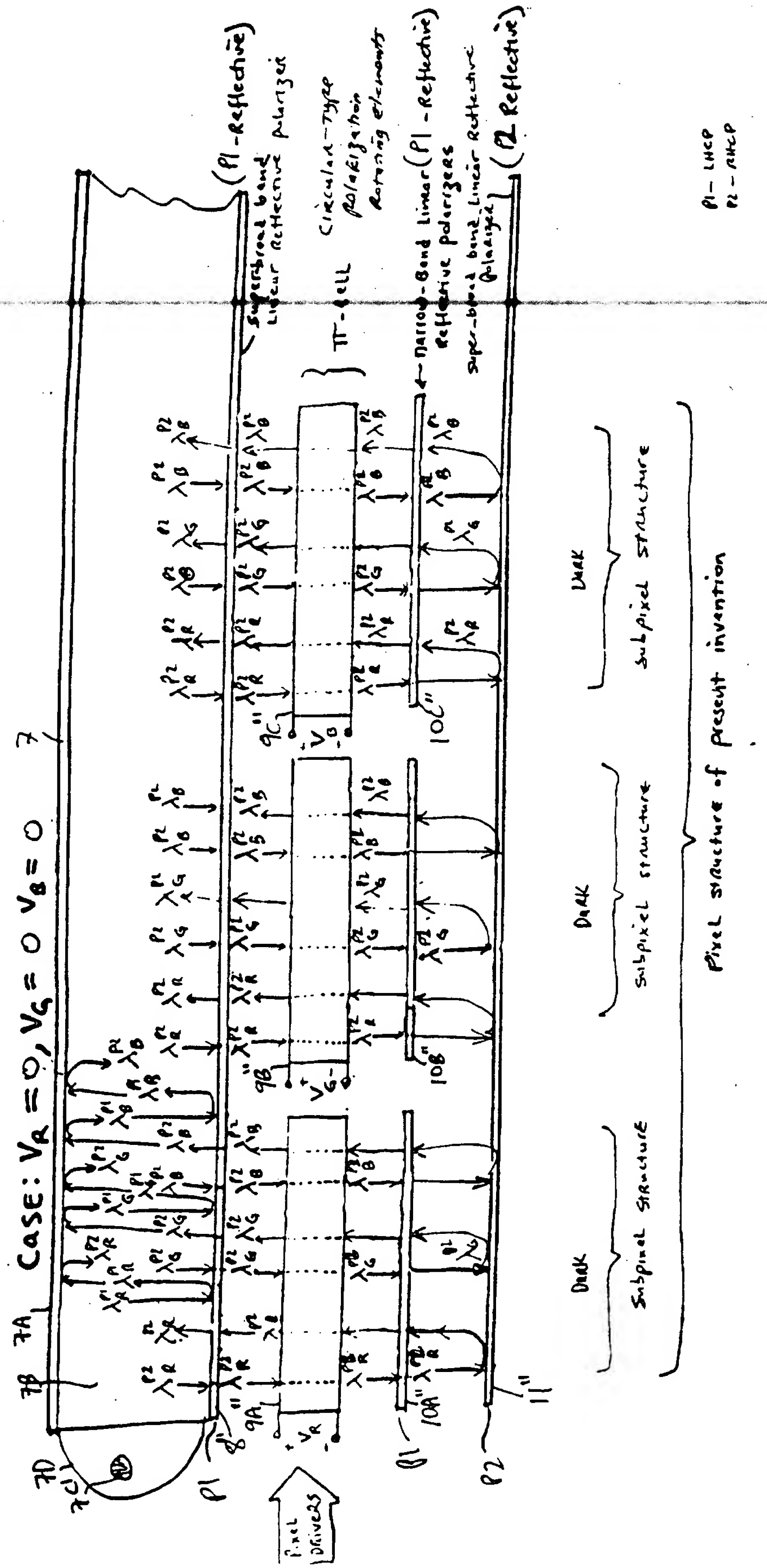
CASE: $V_R = O, V_G = O\ V_B = O$
(P1-Reflective)
Superbroad band Linear Reflective polarizer
Circular-Type Polarization Rotating elements
π-cell
Narrow-Band Linear (P1-Reflective) Reflective polarizers
Super-broad band Linear Reflective Polarizer
(P2 Reflective)
P1 – LHCP
P2 – RHCP
Dark
Subpixel Structure
Pixel structure of present invention
Pixel Drivers

FIG. 4A1

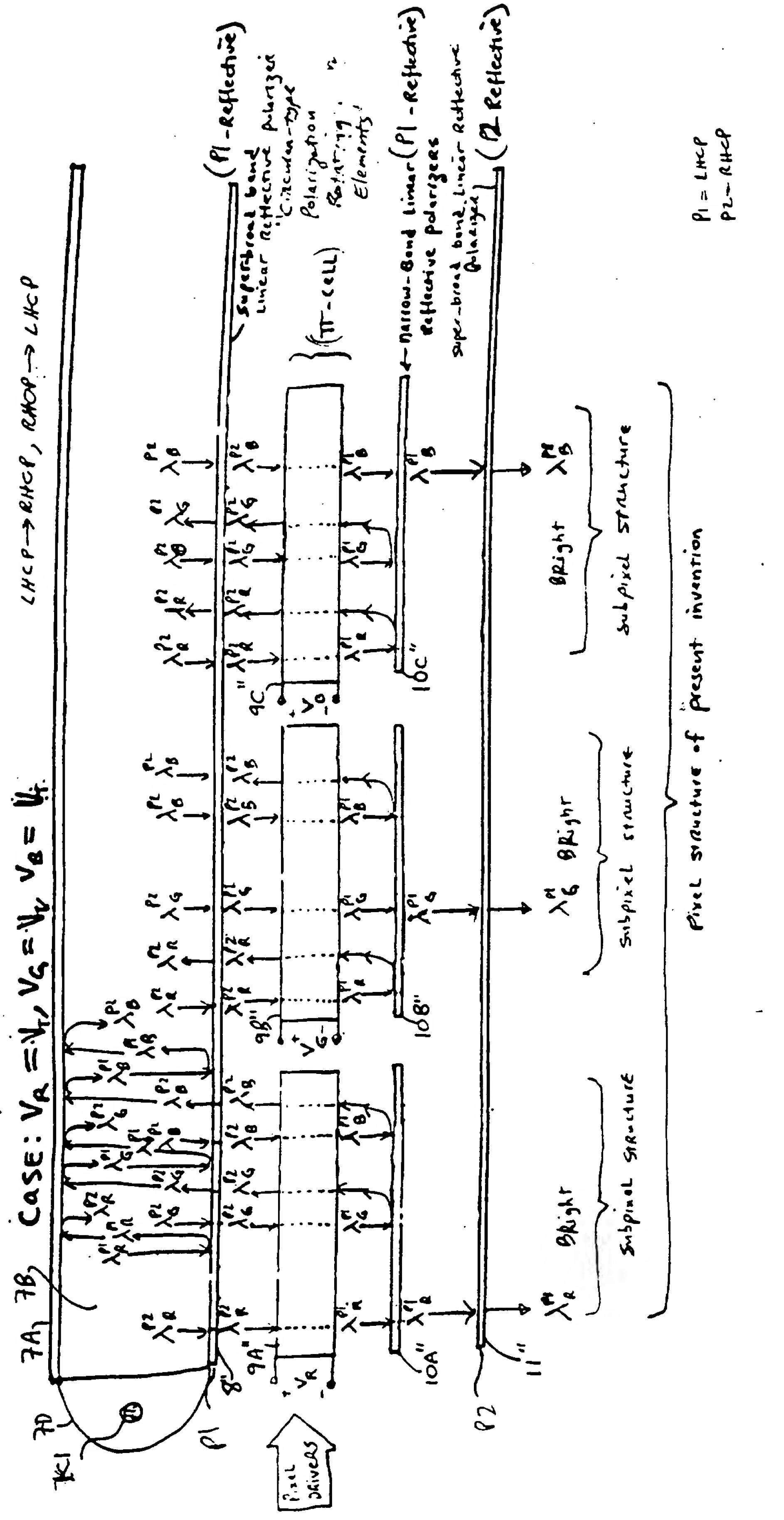
CASE: $V_R = V_T$, $V_G = V_T$, $V_B = V_T$
LHCP → RHCP, RHCP → LHCP
(P1-Reflective)
Superbroad band Linear Reflective polarizer
"Circular-type Polarization Rotating Elements"
(π-cell)
Narrow-Band linear (P1-Reflective) Reflective polarizers
Super-broad band linear Reflective polarizer
(P2 Reflective)
Bright
Subpixel structure
Pixel structure of present invention
P1 = LHCP
P2 = RHCP
Pixel Drivers

FIG. 4A2

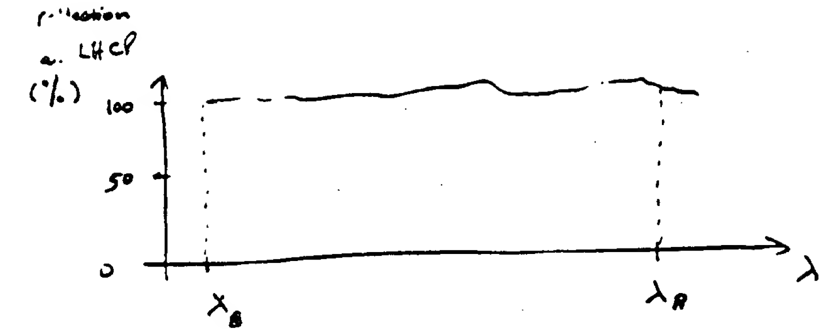

FIG. 4B

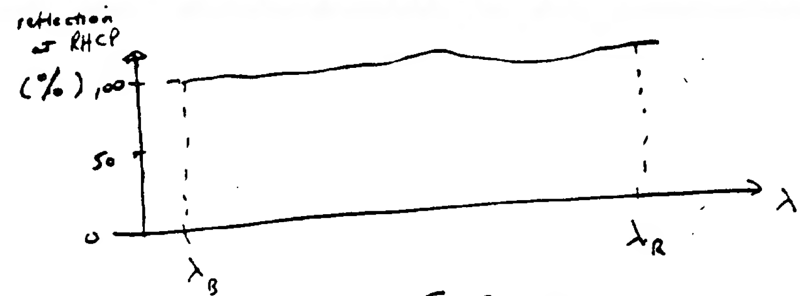

FIG. 4C

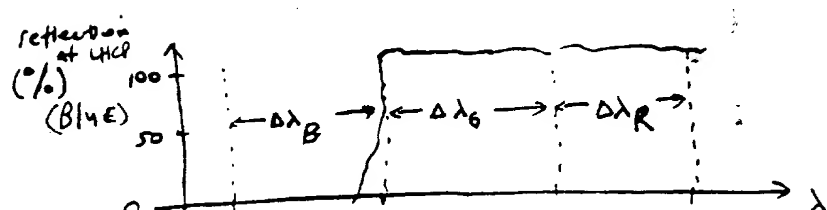

FIG. 4D

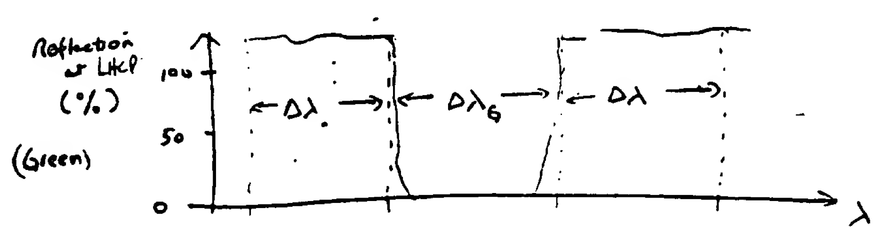

FIG. 4E

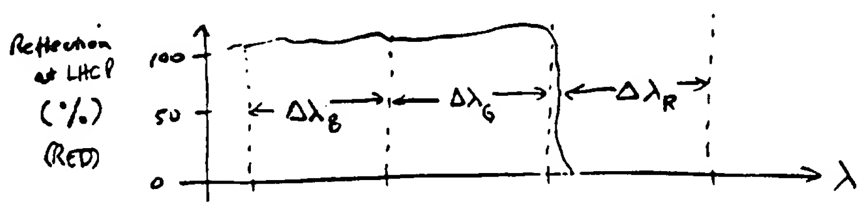

FIG. 4F

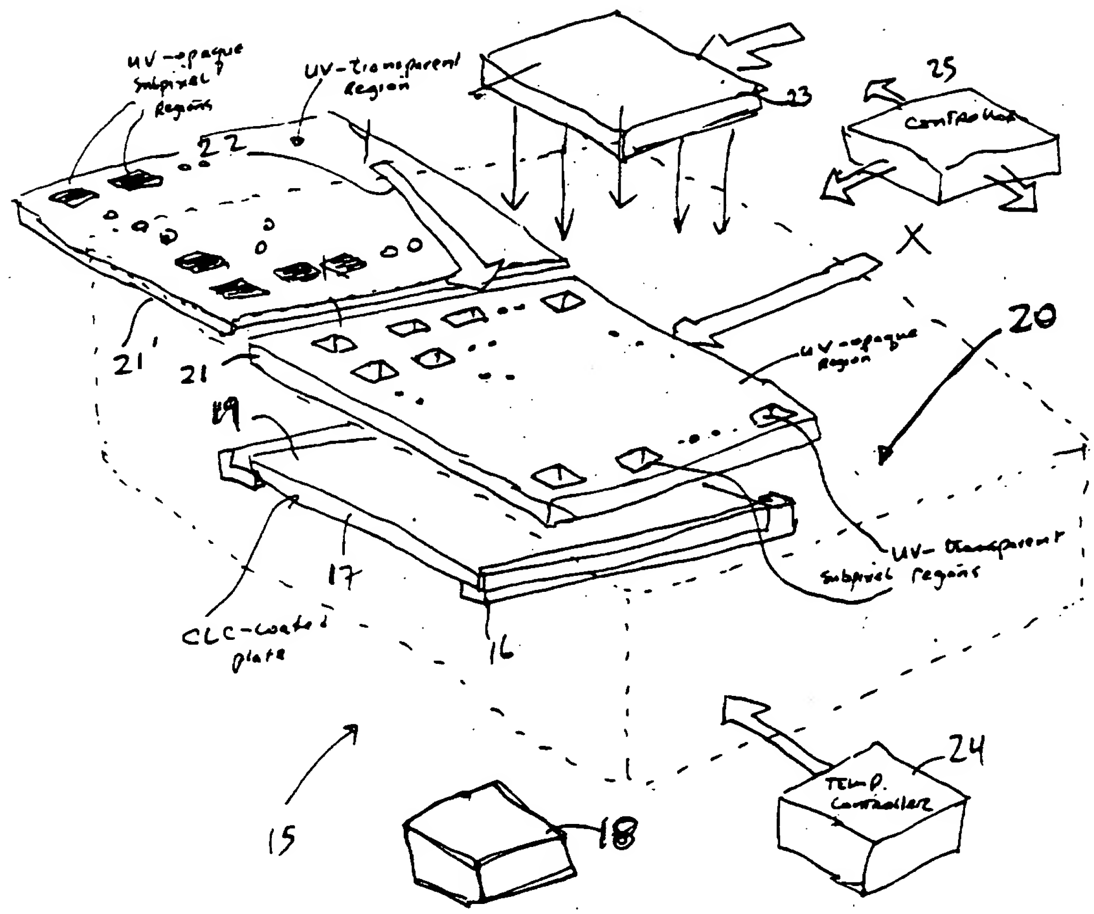
UV-opaque subpixel regions
UV-transparent region
22
23
25
Controller
X
20
21'
21
UV-opaque region
19
17
UV-transparent subpixel regions
CLC-coated plate
16
15
24
Temp. controller
18

FIG. 5

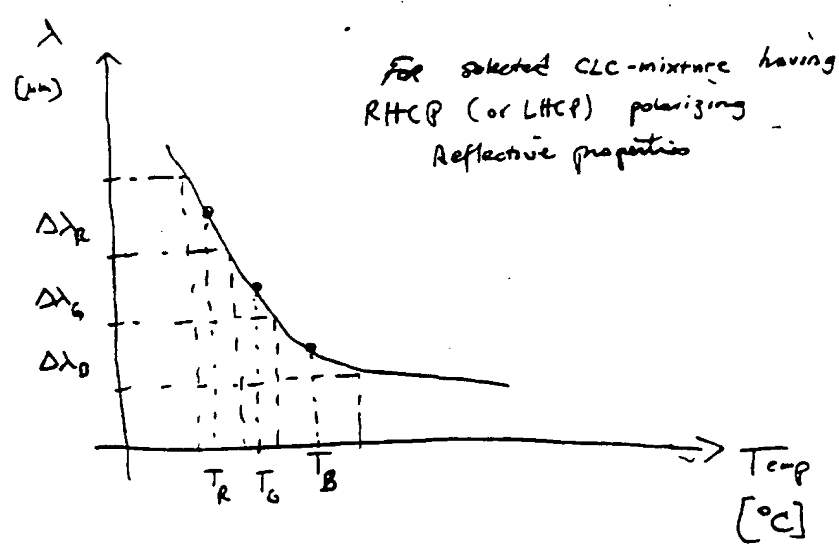
λ
(μm)
For selected CLC-mixture having RHCP (or LHCP) polarizing reflective properties
Δλ_R
Δλ_G
Δλ_B
T_R
T_G
T_B
Temp
[°C]

FIG. 6

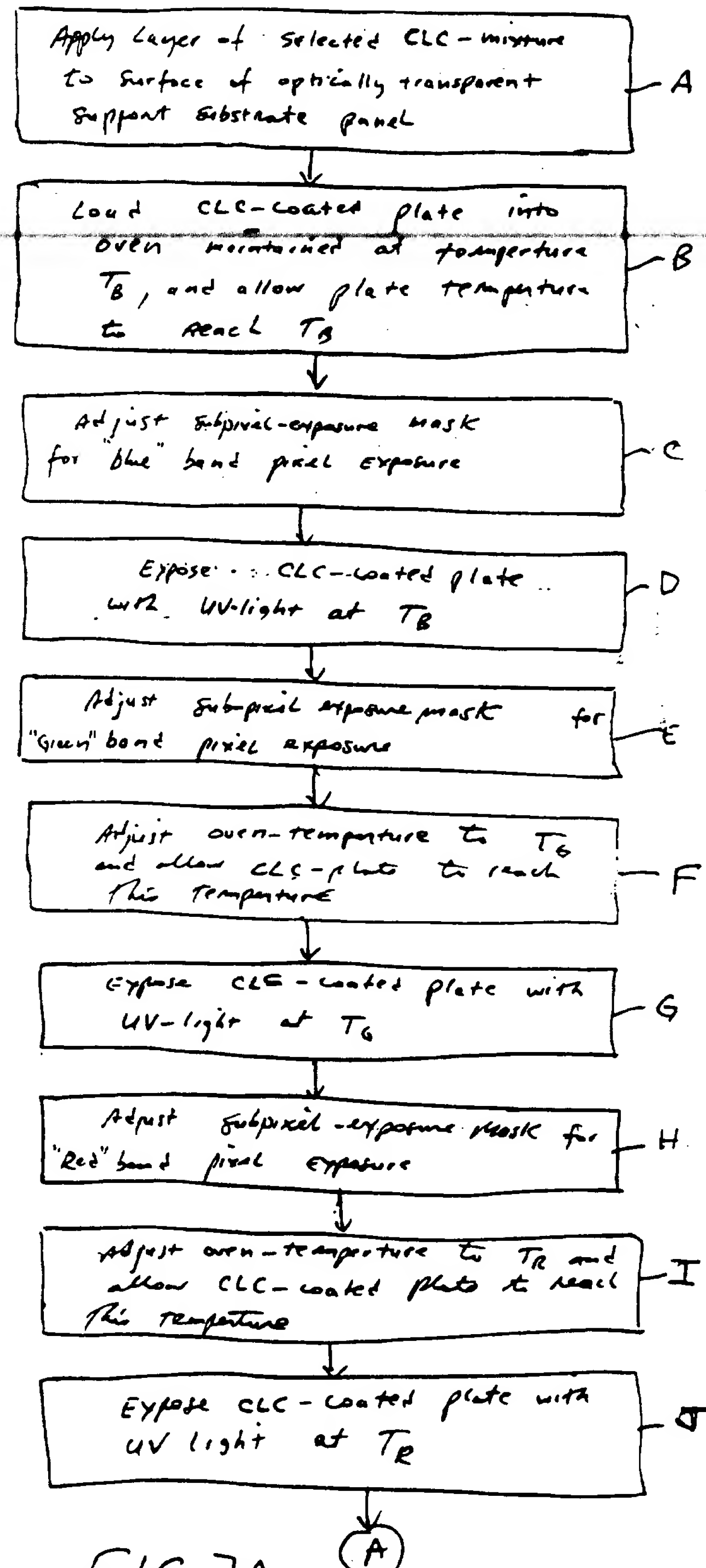
Apply Layer of Selected CLC-mixture to Surface of optically transparent Support Substrate panel
A
Load CLC-coated plate into oven maintained at temperature T_B, and allow plate temperature to reach T_B
B
Adjust Subpixel-exposure mask for "blue" band pixel exposure
C
Expose CLC-coated plate with UV-light at T_B
D
Adjust Sub-pixel exposure mask for "Green" band pixel exposure
E
Adjust oven-temperature to T_G and allow CLC-plate to reach this temperature
F
Expose CLC-coated plate with UV-light at T_G
G
Adjust Subpixel-exposure mask for "Red" band pixel exposure
H
Adjust oven-temperature to T_R and allow CLC-coated plate to reach this temperature
I
Expose CLC-Coated plate with UV light at T_R
J
A

FIG. 7A

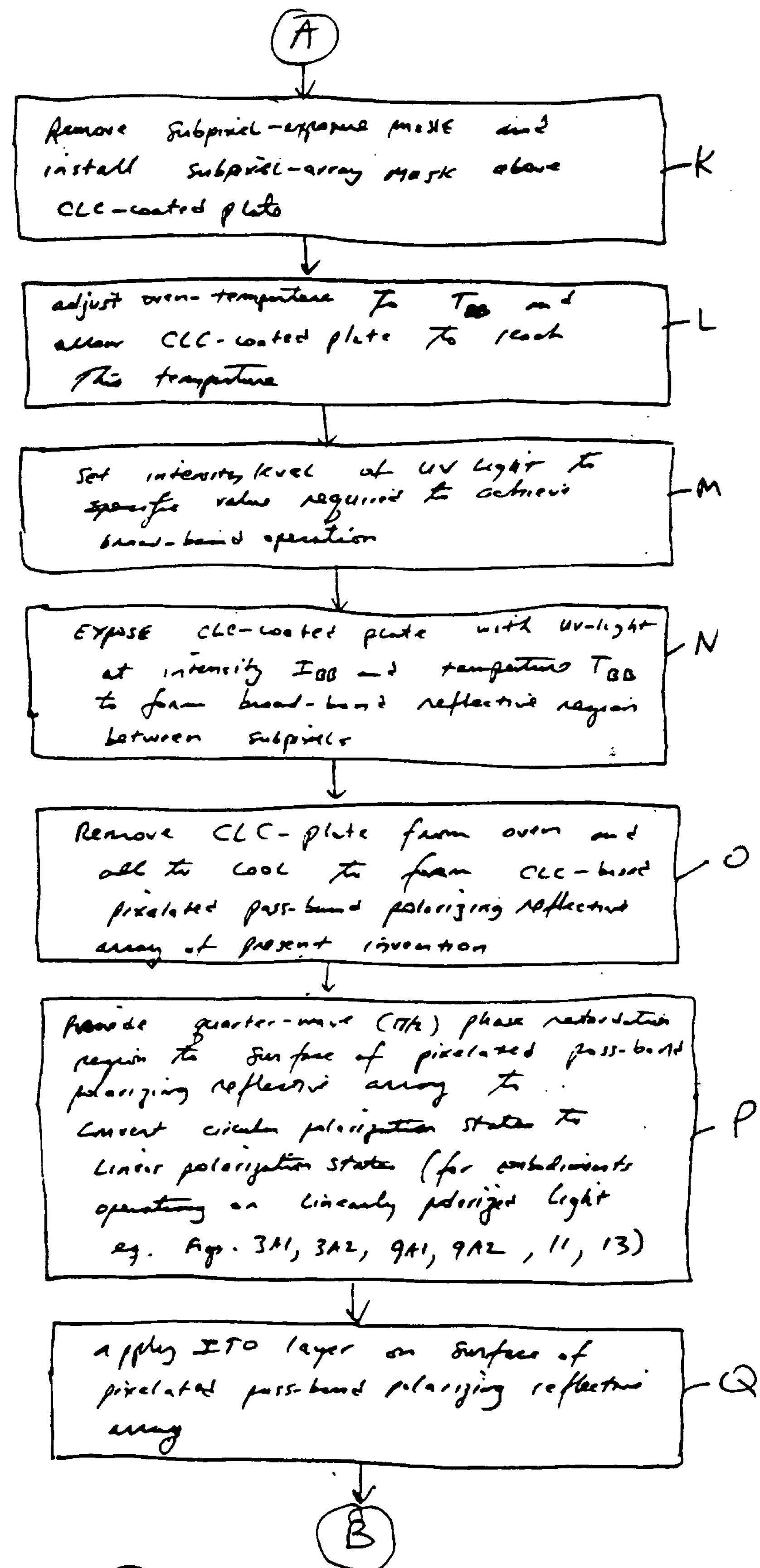
A
Remove subpixel-exposure mask and install subpixel-array mask above CLC-coated plate
K
adjust oven-temperature to T_{BB} and allow CLC-coated plate to reach this temperature
L
Set intensity level of UV light to specific value required to achieve broad-band operation
M
Expose CLC-coated plate with UV-light at intensity I_{BB} and temperature T_{BB} to form broad-band reflective region between subpixels
N
Remove CLC-plate from oven and allow to cool to form CLC-based pixelated pass-band polarizing reflective array of present invention
O
Provide quarter-wave (π/2) phase retardation region to surface of pixelated pass-band polarizing reflective array to convert circular polarization state to linear polarization state (for embodiments operating on linearly polarized light eg. Figs. 3A1, 3A2, 9A1, 9A2, 11, 13)
P
apply ITO layer on surface of pixelated pass-band polarizing reflective array
Q
B

FIG. 7B

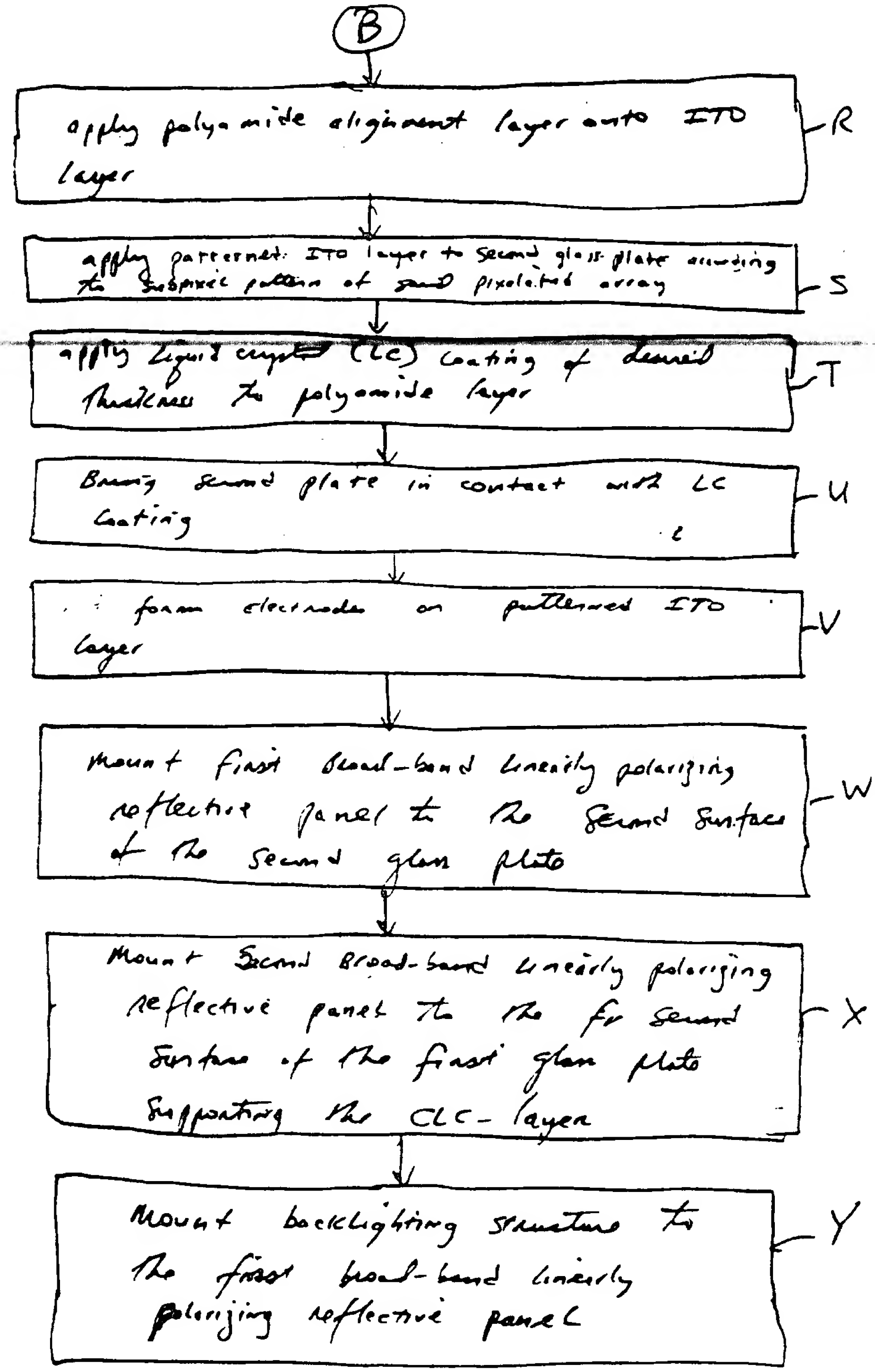
B
apply polyamide alignment layer onto ITO layer
R
apply patterned ITO layer to second glass plate according to subpixel pattern of said pixelated array
S
apply liquid crystal (LC) coating of desired thickness to polyamide layer
T
Bring second plate in contact with LC coating
U
form electrodes on patterned ITO layer
V
Mount first broad-band linearly polarizing reflective panel to the second surface of the second glass plate
W
Mount second broad-band linearly polarizing reflective panel to the ~~fr~~ second surface of the first glass plate supporting the CLC-layer
X
Mount backlighting structure to the first broad-band linearly polarizing reflective panel
Y

FIG. 7C

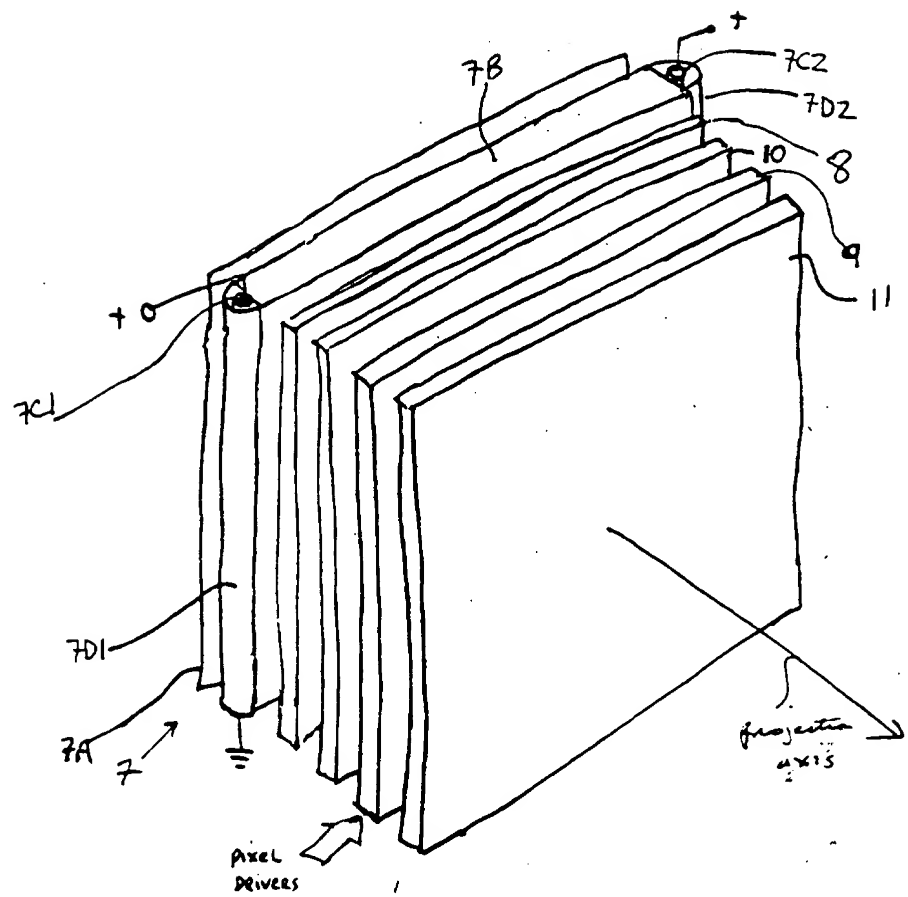
7B
7C2
7D2
8
10
9
11
+
+ 0
7C1
7D1
7A
7
PIXEL DRIVERS
projection axis

FIG. 8

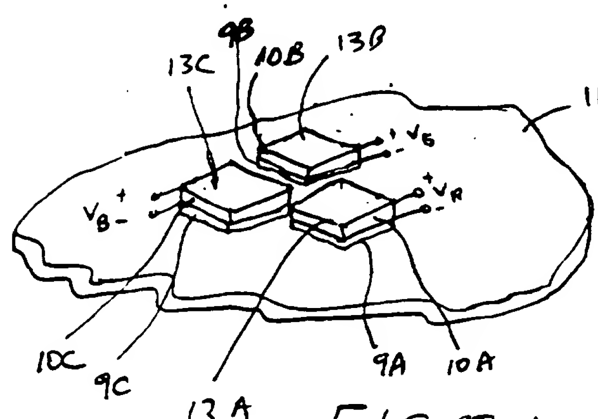
9B
13C
10B
13B
11
V_G
V_B
V_R
10C
9C
13 A
9A
10A

FIG. 8A

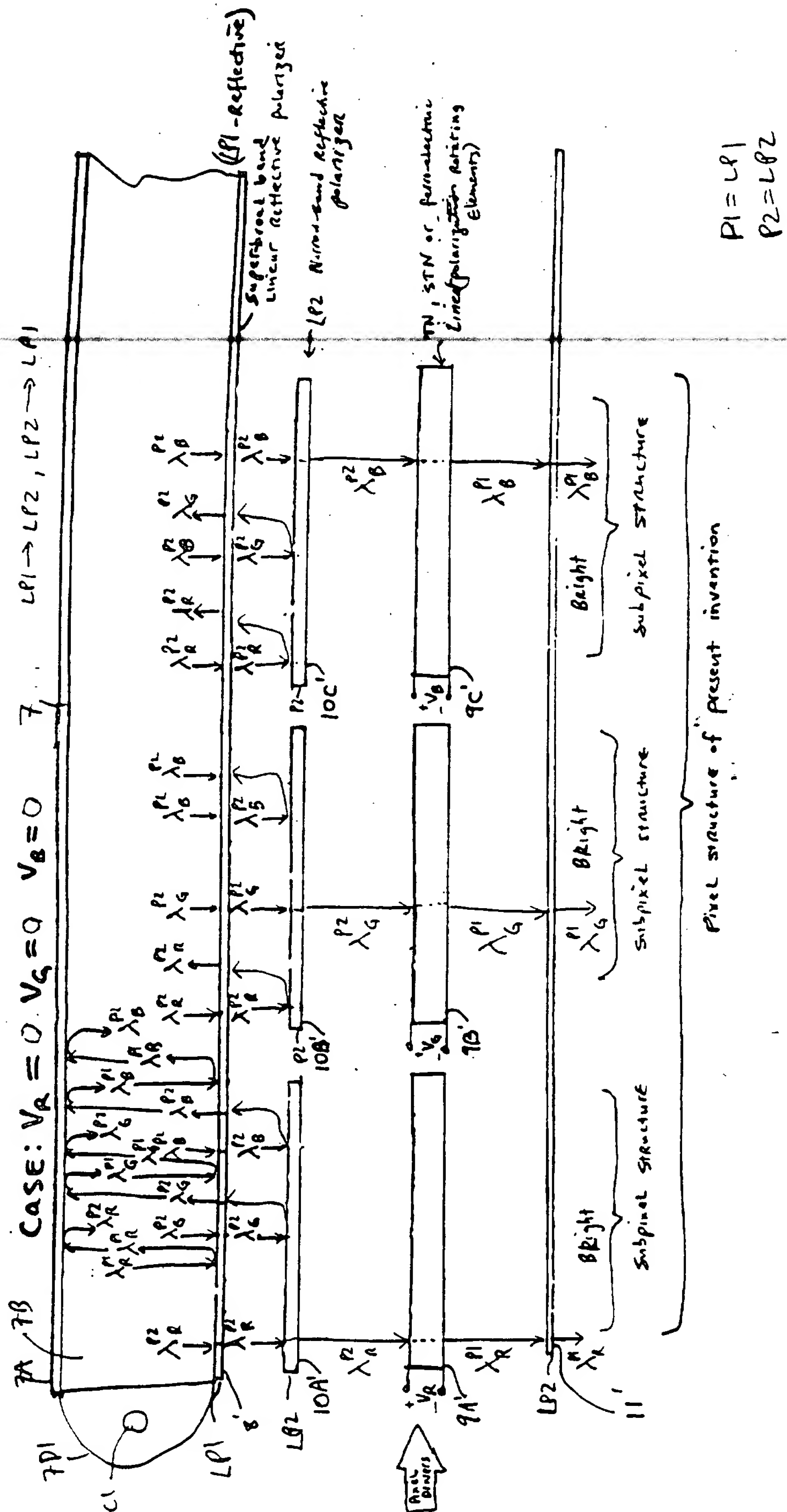
CASE: $V_R = 0$ $V_G = 0$ $V_B = 0$
LP1 → LP2 , LP2 → LP1
Bright
Subpixel structure
Pixel structure of present invention
P1 = LP1
P2 = LP2

FIG. 9A1

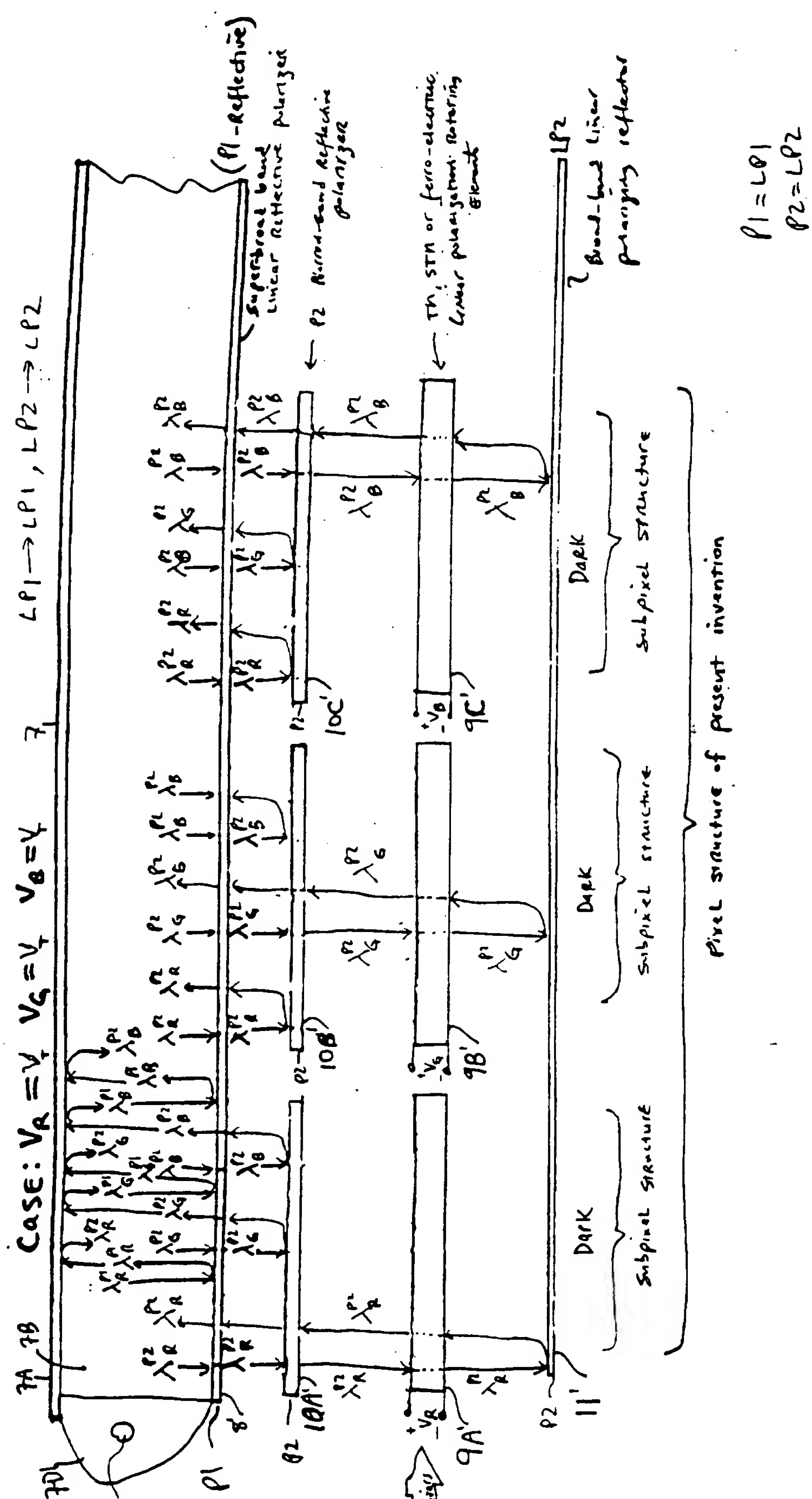
Case: $V_R = V_T$ $V_G = V_T$ $V_B = V_T$
LP1 → LP1, LP2 → LP2
(P1-Reflective)
Superbroad band Linear Reflective polarizer
P2 Narrow-band Reflective polarizer
TN, STN or ferro-electric Linear polarization Rotating Element
LP2
Broad-band Linear polarizing reflector
Dark
subpixel structure
Pixel structure of present invention
P1 = LP1
P2 = LP2
7A
7B
7D
7C1
P1
8
P2
10A'
10B'
10C'
9A'
9B'
9C'
11'

FIG. 9A2

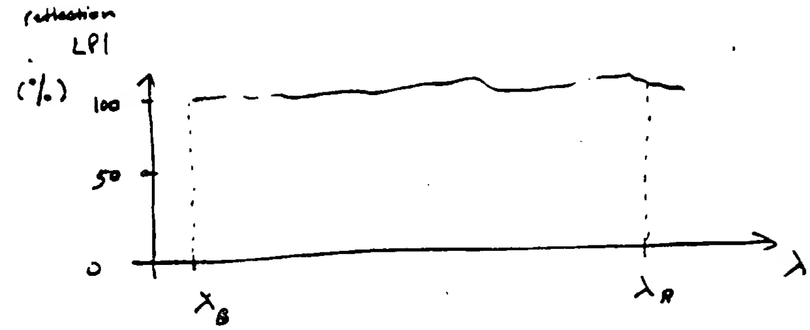

FIG. 9B

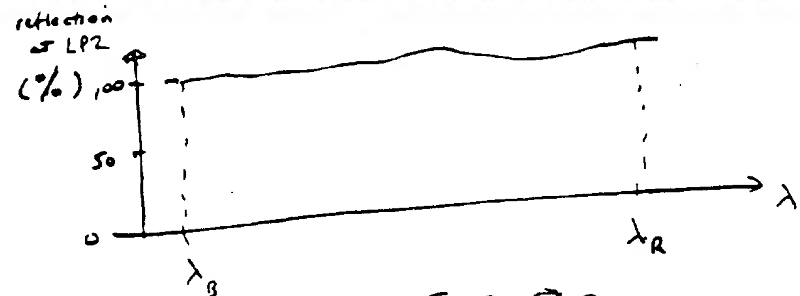

FIG. 9C

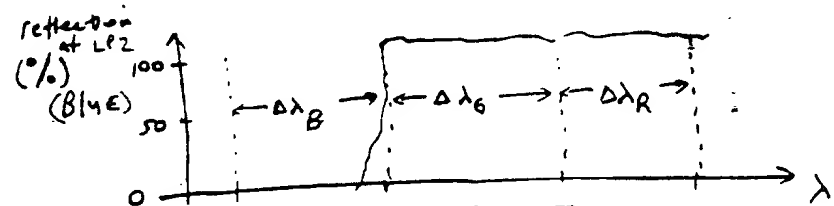

FIG. 9D

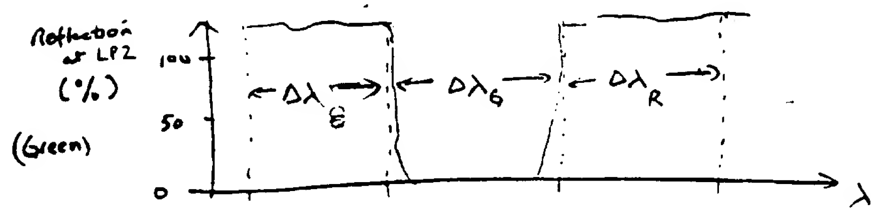

FIG. 9E

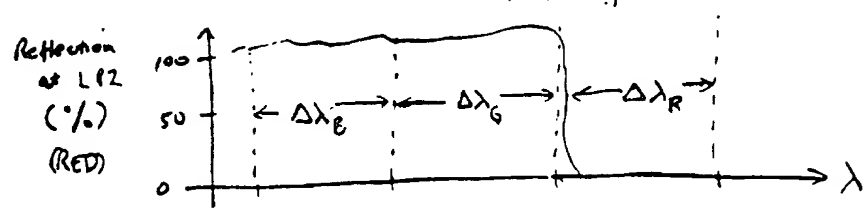

FIG. 9F

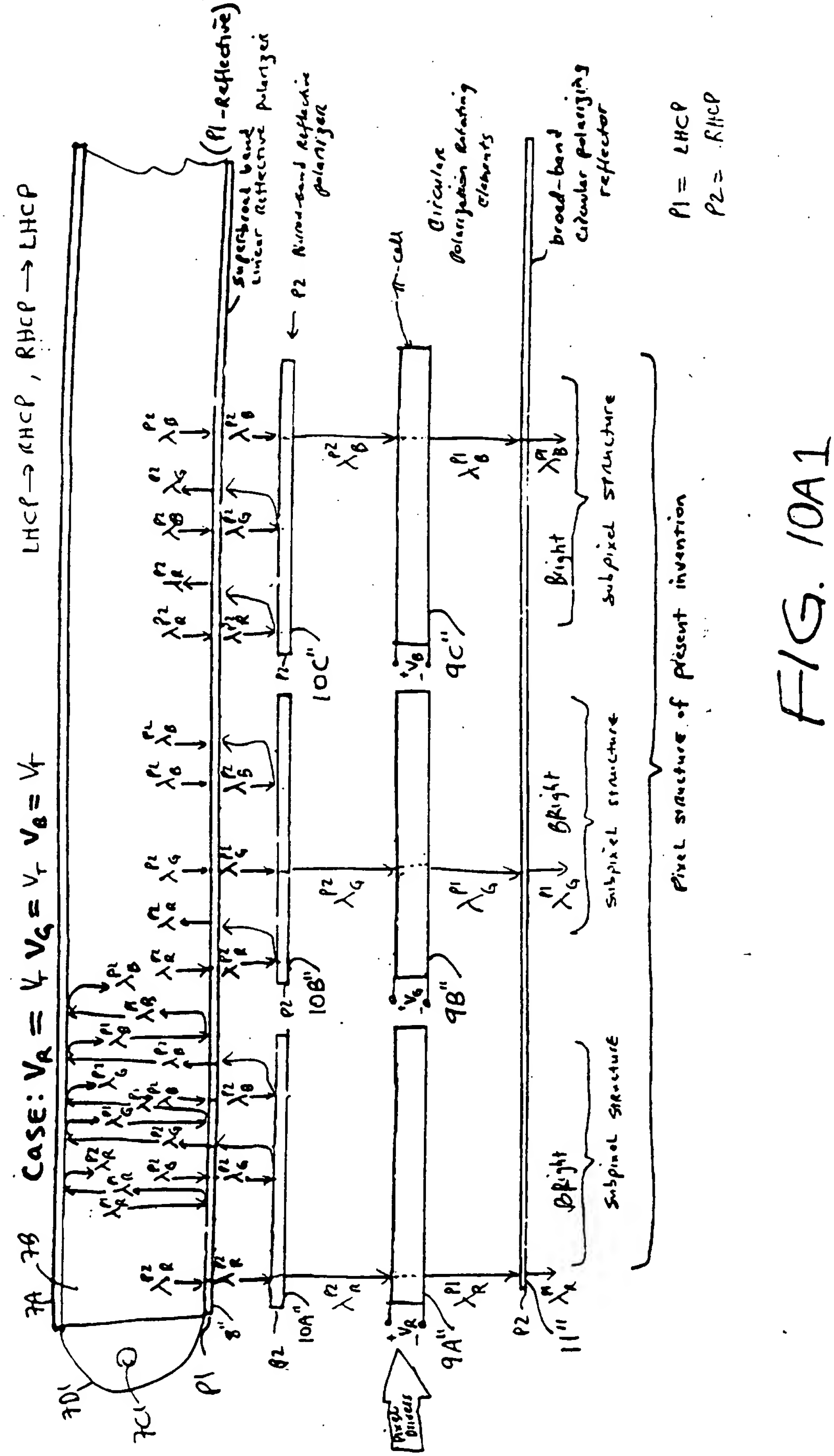
CASE: $V_R = V_T$ $V_G = V_T$ $V_B = V_T$
LHCP → RHCP , RHCP → LHCP
(P1 - Reflective)
Superbroad band linear reflective polarizer
P2 Narrow-band reflective polarizer
π-cell
Circular polarization rotating elements
broad-band circular polarizing reflector
Bright
subpixel structure
Pixel structure of present invention
P1 = LHCP
P2 = RHCP
10A''
10B''
10C''
9A''
9B''
9C''
11''
8''
7A
7B
7C'
7D'

FIG. 10A1

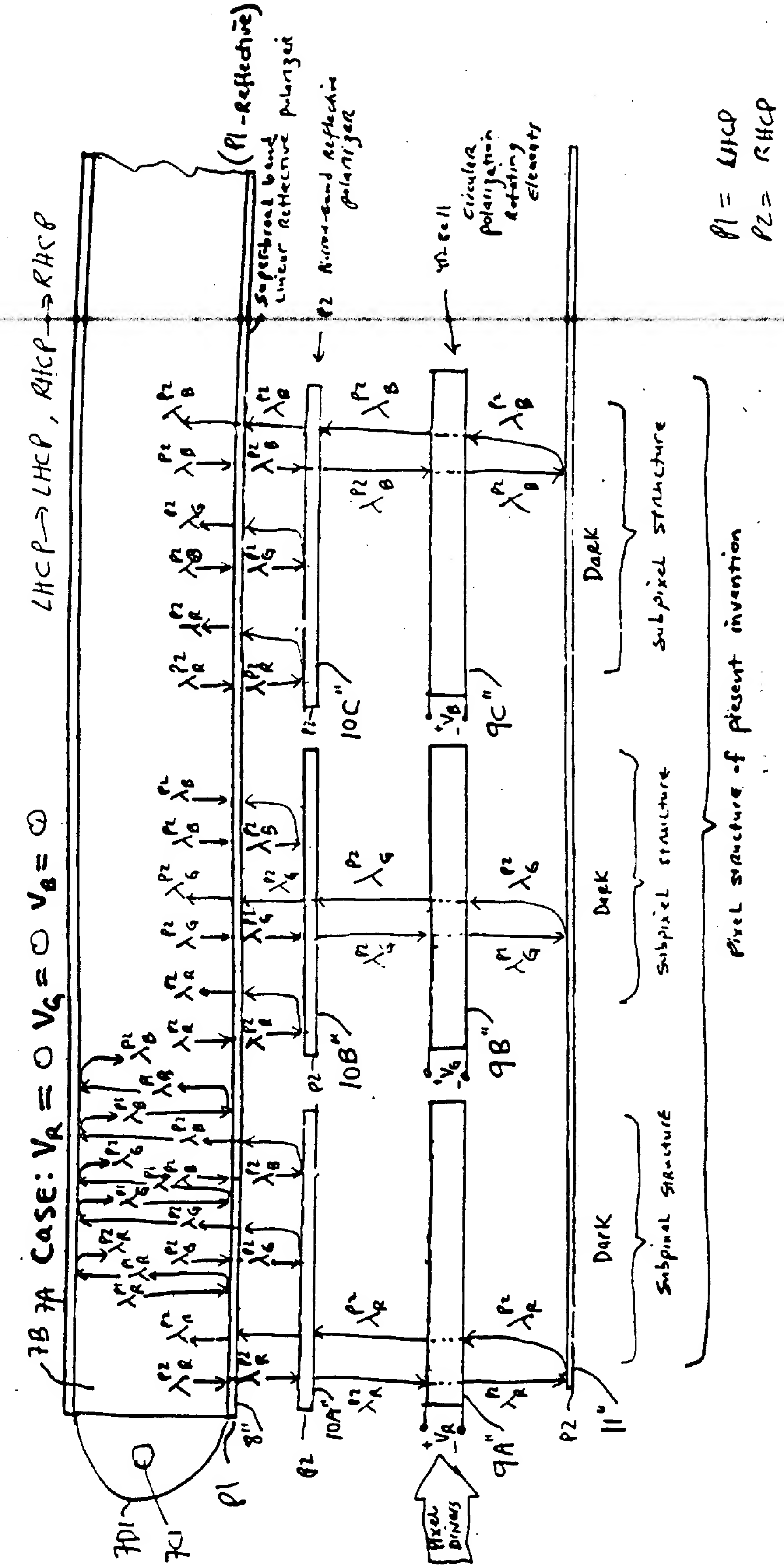
CASE: $V_R = 0$ $V_G = 0$ $V_B = 0$
LHCP → LHCP, RHCP → RHCP
(P1 - Reflective)
Superbroad band linear reflective polarizer
P2 Narrow-band reflective polarizer
π-cell
Circular polarization rotating elements
P1 = LHCP
P2 = RHCP
Dark
Subpixel structure
Pixel structure of present invention
Pixel Drives
7B
7A
7D1
7C1
P1
8"
P2
10A"
10B"
10C"
9A"
9B"
9C"
11"
V_R
V_G
V_B

FIG. 10A2

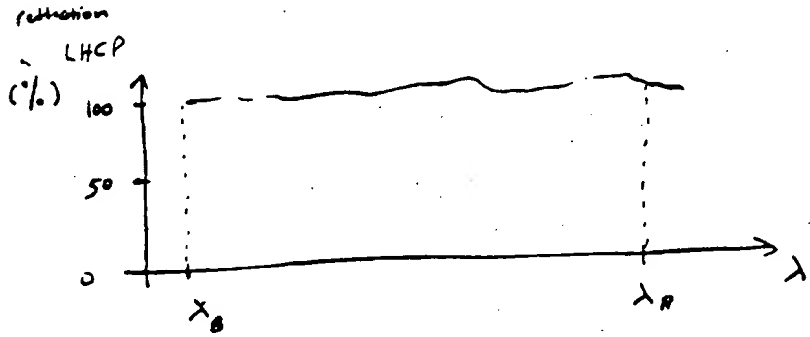

FIG. 10B

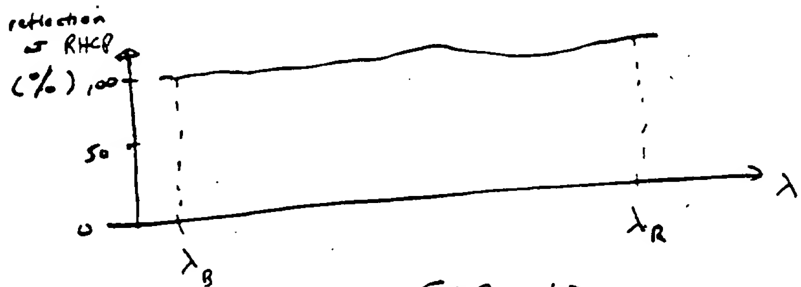

FIG. 10C

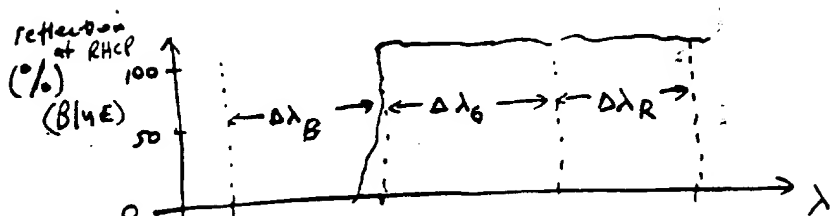

FIG. 10D

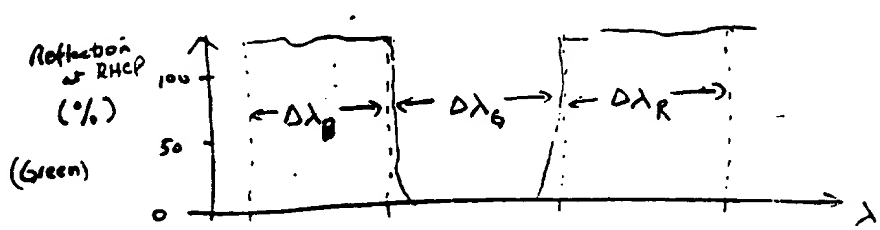

FIG. 10E

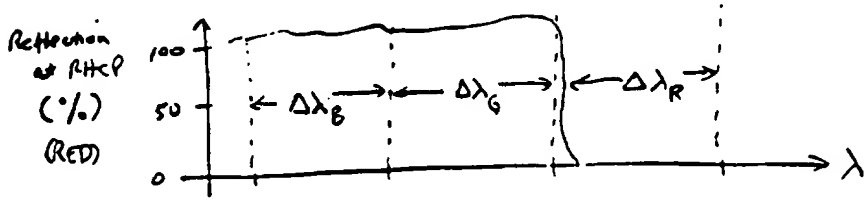

FIG. 10F

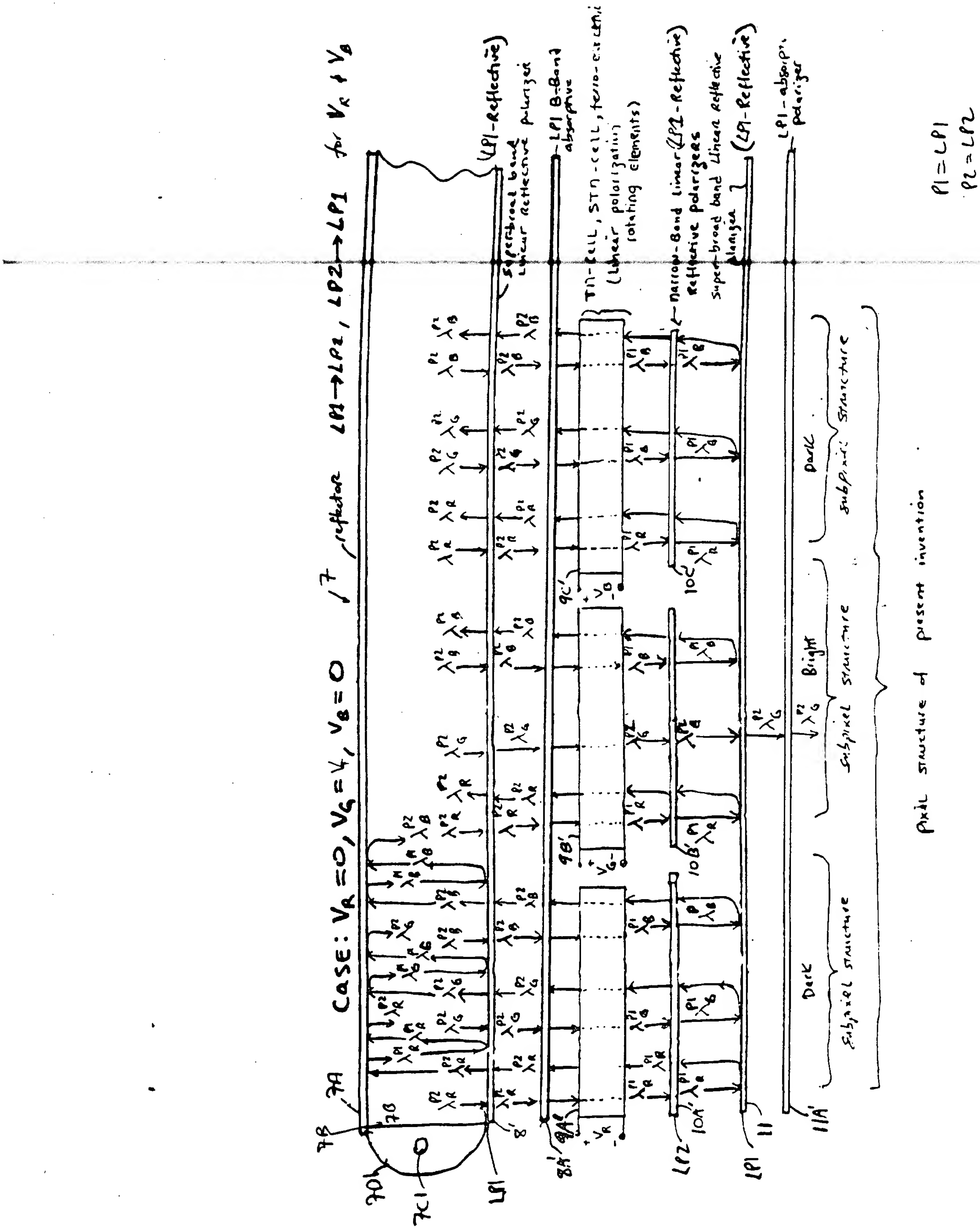
CASE: V_R = 0, V_G = V, V_B = 0 LP1→LP2, LP2→LP1 for V_R & V_B
reflector
(LP1-Reflective)
Superbroad band Linear Reflective polarizer
LP1 B-Band absorptive
TN-cell, STN-cell, ferro-electric (Linear polarization rotating elements)
Narrow-Band linear (LP2-Reflective) Reflective polarizers
Super-broad band Linear Reflective polarizer (LP1-Reflective)
LP1-absorptive polarizer
Dark subpixel structure
Bright subpixel structure
Dark subpixel structure
Pixel structure of present invention
P1 = LP1
P2 = LP2

FIG.11

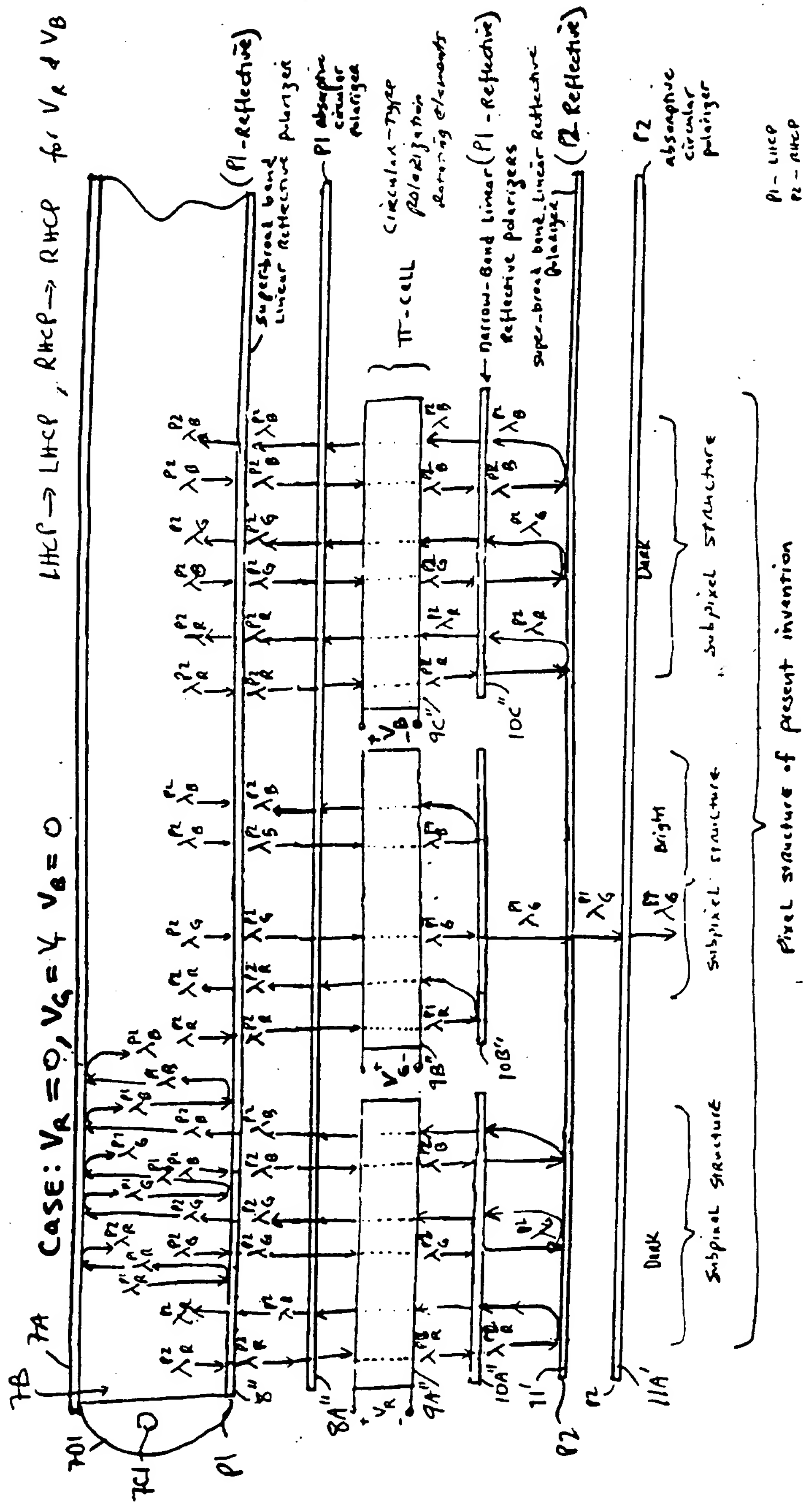
CASE: V_R = 0, V_G = V, V_B = 0
LHCP → LHCP, RHCP → RHCP for V_R & V_B
(P1-Reflective)
Super-broad band linear Reflective polarizer
P1 absorptive circular polarizer
Circular-type polarization Rotating elements
π-cell
Narrow-Band linear Reflective polarizers
(P1-Reflective)
super-broad band linear Reflective polarizer
(P2 Reflective)
P2 absorptive circular polarizer
P1 - LHCP
P2 - RHCP
Dark
Bright
Dark
subpixel structure
subpixel structure
subpixel structure
Pixel structure of present invention
7A
7B
701
7L
P1
8"
8A"
9A"
10A"
11'
P2
11A'
9B"
10B"
9C"
10C"

FIG. 12

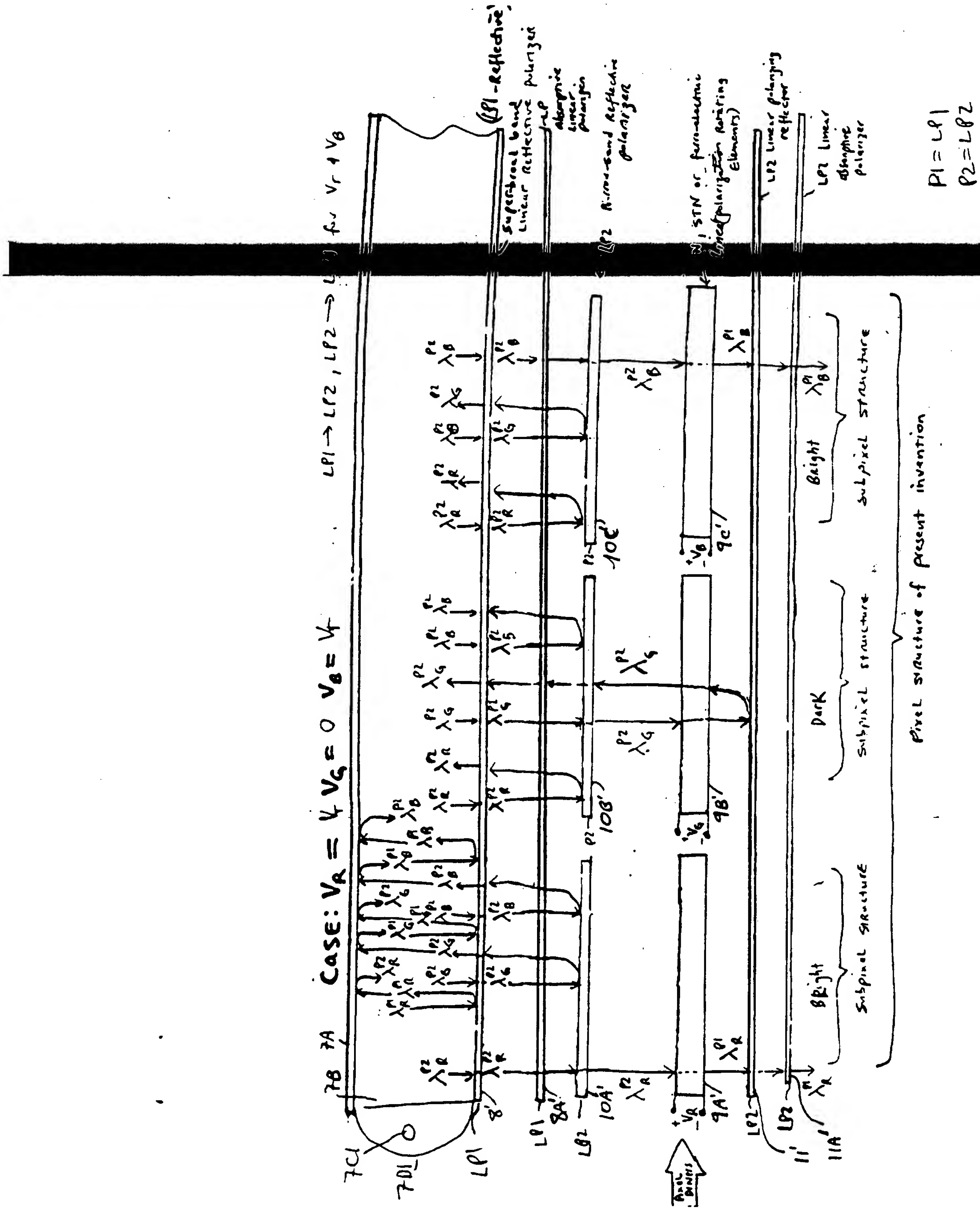
Superbroad band Linear Reflective polarizer
LP2 Narrow-band Reflective polarizer
LP2 linear polarizing reflector
LP2 linear absorptive polarizer
Bright
Dark
Bright
Subpixel structure
Pixel structure of present invention
P1 = LP1
P2 = LP2

FIG. 13

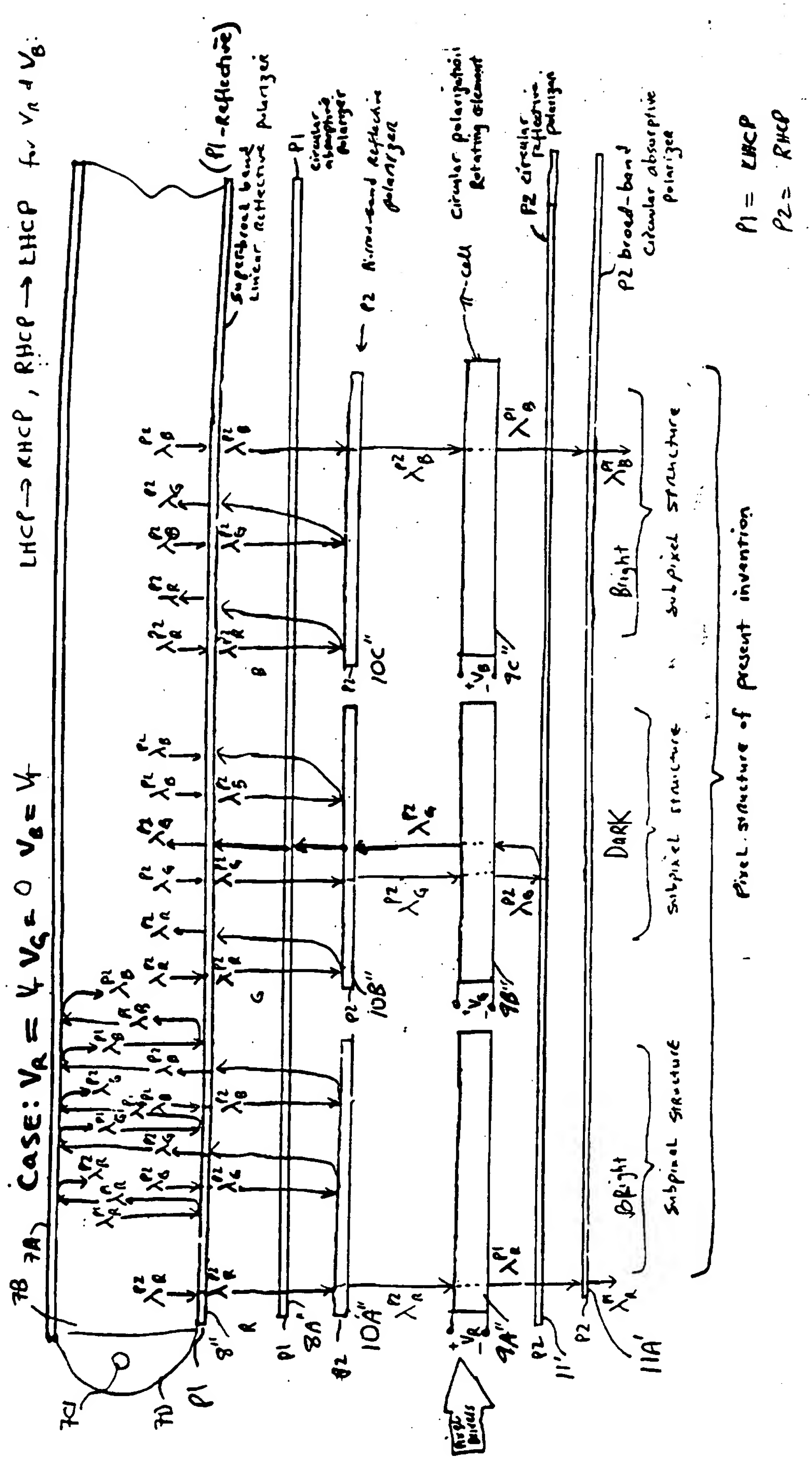
CASE: V_R = V_t V_G = 0 V_B = V_t
LHCP → RHCP , RHCP → LHCP for V_R & V_B
P1 = LHCP
P2 = RHCP
Bright
subpixel structure
DARK
subpixel structure
Bright
subpixel structure
Pixel structure of present invention
P1 circular absorptive polarizer
P2 broad-band circular absorptive polarizer
Superbroad band linear reflective polarizer
P2 circular reflective polarizer
Circular polarization rotating element
π-cell
10A''
10B''
10C''
9A''
9B''
9C''
8A''
8''
11''
11A'
7A
7B
7C
7D

FIG.14

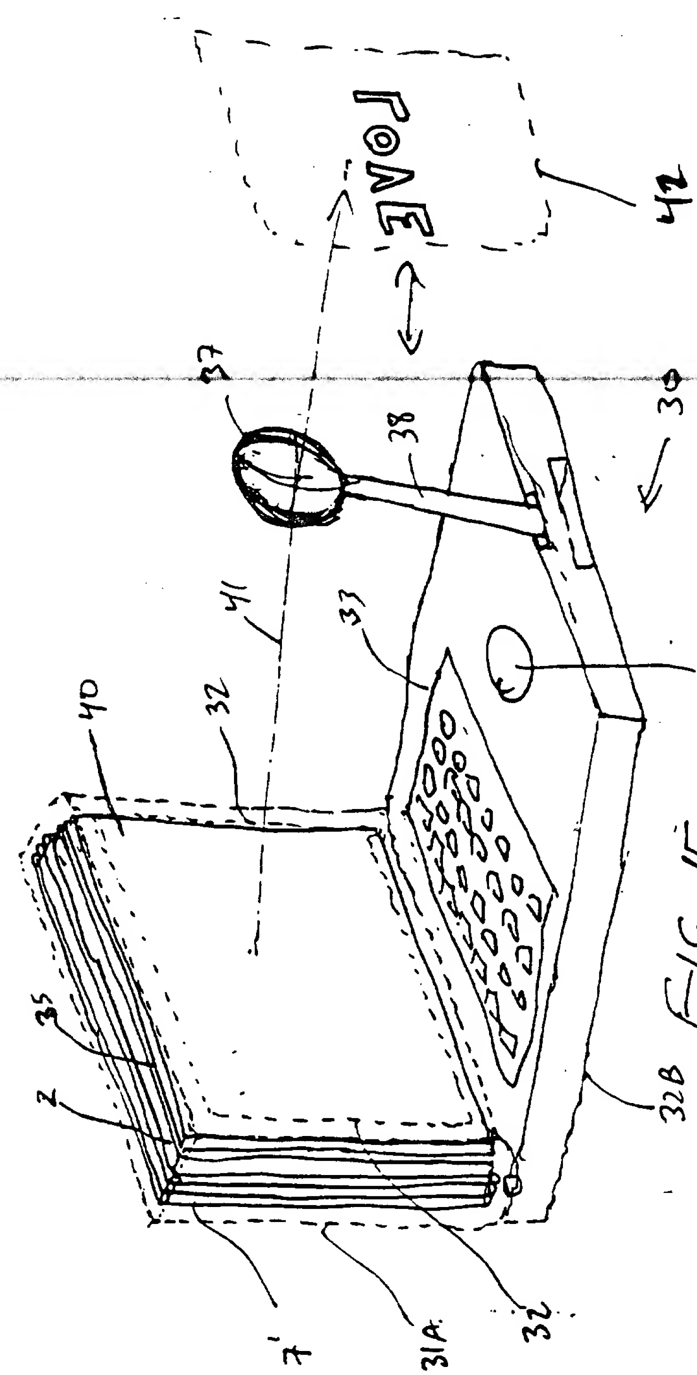

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16907

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.
US CL :156/345; 313/497; 349/61, 62, 74, 80, 98, 115, 176; 362/27
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 156/345; 313/497; 349/61, 62, 74, 80, 98, 115, 176; 362/27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,325,218 A (WILLETT ET AL) 28 June 1994 (28.06.94), see the entire document.	1-81, 84-154, 160-162
Y	US 5,046,826 A (IWAMOTO ET AL) 10 September 1991 (10.09.91), see the entire document.	1-81, 84-154, 160-162
Y	US 4,610,507 A (KAMAMORI ET AL) 09 September 1986 (09.09.86), see the entire document.	1-81, 84-154, 160-162
A, P	US 5,650,865 A (SMITH) 22 July 1997 (22.07.97), see the entire document.	1-81, 84-154, 160-162
A	US 5,418,631 A (TEDESCO) 23 May 1995 (23.05.95), see the entire document.	1-81, 84-154, 160-162

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 JANUARY 1998	10 FEB 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	WALTER MALINOWSKI
Facsimile No. (703) 308-7726	Telephone No. (703) 308-4842

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16907

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos.: 82, 83
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

claims 82, 83 (page 107) are missing.

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Extra Sheet

1. [X] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[X] No protest accompanied the payment of additional search fees.

International Search Report

International application No.
PCT/US97/16907

1. This International Search Authority has found 7 inventions claimed in the International Application covered by the claims indicated below:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claim(s)1-15 and 119-134, drawn to a liquid crystal display panel having light producing means, spatial intensity modulation means, spectral filtering means, and systemic light recycling means in which the polarization state of the light is not described, classified in class 349, subclass 61.

Group II, claim(s) 16-81, 84-118 and 136-154, drawn to a liquid crystal display panel having light producing means, spatial intensity modulation means, and spectral filtering means, in which the polarization state of the light is selectively transmitted, classified in class 349, subclass 84.

Group III, claim(s) 135, drawn to a cascaded backlighting structure in a color LCD panel, classified in class 362, subclass 27.

Group IV, claims 155-157, drawn to a computer controlled system for fabricating a reflective panel, classified in class 313, subclass 497.

Group V, claim 158, drawn to a method for fabricating a spectral filtering panel, classified in class 349, subclass 187.

Group VI, claims 159-162, drawn to an apparatus for fabricating a spectral filtering panel, classified in class 156, subclass 345.

This application contains claims directed to more than one species of the generic invent n. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be searched, the appropriate additional search fees must be paid.

The species are as follows:

group II, species a) drawn to operation with circularly polarized light
group II, species b) drawn to operation with linearly polarized light

The claims are deemed to correspond to the species listed above in the following manner:

group II, species a) claims 16-35 and 56-74
group II, species b) claims 36-55, 75-81, and 84-93.

The following claims are generic: 94-118 and 136-154 (group II).

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be searched, the appropriate additional search fees must be paid.

and it considers that the International Application does not comply with the requirements of unity of invention (Rules 13.1, 13.2 and 13.3) for the reasons indicated below:

The inventions listed as Groups I-VI do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: group I concerns a color display system that does not claim use with light of a particular polarization, group II concerns a color display system which claims use of polarized light, group III concerns cascaded backlights, group IV concerns a computer controlled system for fabricating a reflective panel, group V concerns a method for fabricating a spectral filtering panel, and group VI concerns an apparatus for fabricating a spectral filtering panel.

The species listed above do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons: in species a) of group II,

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/16907

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (6):

C23F 1/02; HO1J 1/62, 63/04; G02F 1/1335, 1/1347; C09K 19/02; G01D 11/28

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

APS, EPOABS, JPOABS
search terms: cholesteric, clc, cascaded, illumination, lighting, backlighting, systemic, recycling, color filter, colour filter, liquid crystal

the device operates with circularly polarized light and in species b) of group II, the device operates with linearly polarized light.